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ESBWR Test and Analysis Program Description

Supplement 1 - Discussion of PIRT Parameters

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REVISION 1

Revision 1 incorporates changes resulting from NRC review of the document. Changes are indicated in the report by a line in the left margin as shown for this paragraph and by footnotes that reference the specific Request for Additional Information (RAI).

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Abbreviations and Acronyms

ABWR	Advanced Boiling Water Reactor
ADS	Automatic Depressurization System
APRM	Average Power Range Monitor
ARI	Alternate Rod Insertion
ASME	American Society of Mechanical Engineers
ATLAS	GE's 8.6 MW Heat Transfer Loop
ATWS	Anticipated Transients Without Scram
Bldn	Blowdown
BO	Boiloff
BWR	Boiling Water Reactor
C&FWS	Condensate and Feed Water System[1]
CACS	Containment Atmospheric Control System
CCFL	Counter Current Flow Limiting
CISE	Centro Informazioni Studi Esperienze
COL	Combined Operating License
CPR	Critical Power Ratio
CRD	Control Rod Drive
CTP	Core Thermal Power
CRIEPI	Central Research Institute of Electric Power Industry
CSAU	Code Scaling, Applicability and Uncertainty
CSHT	Core Spray Heat Transfer
DBA	Design Basis Accident
DC	Downcomer
DPV	Depressurization Valve
DW, D/W	Drywell
EBWR	Experimental Boiling Water Reactor
ECCS	Emergency Core Cooling System
EOPs	Emergency Operating Procedures
ESF	Engineered Safety Feature
FAPCS	Fuel and Auxiliary Pool Cooling System
FIST	BWR Full Integral Simulation Test
FIX	Swedish Test Loop Used for Testing External Pump Circulation
FMCRD	Fine Motion Control Rod Drive
FRIGG	Research Heat Transfer Loop Operated for Danish Atomic Energy Commission
FW	Feedwater

[1] ESBWR RAI 208

Abbreviations and Acronyms (Continued)

FWCS	Feedwater Control System
GDCS	Gravity-Driven Cooling System
GE	General Electric Company
GEXL	General Electric Critical Quality Boiling Length Correlation
GIRAFFE	Gravity-Driven Integral Full-Height Test for Passive Heat Removal
GIST	GDCS Integral System Test
HCU	Hydraulic Control Unit
HVAC	Heating, Ventilating and Air Conditioning
IC	Isolation Condenser
ICS	Isolation Condenser System
INEL	Idaho National Engineering Laboratory
LANL[2]	Los Alamos National Laboratory
LB	Large Break
LOCA	Loss-Of-Coolant Accident
LOOP	Loss Of Offsite Power
MCPR	Minimum Critical Power Ratio
MIT	Massachusetts Institute of Technology
MPL	Master Parts List
MSIV	Main Steamline Isolation Valve
MSL	Main Steamline
MW	Megawatt
NBS	Nuclear Boiler System
NRC	Nuclear Regulatory Commission
ORNL	Oak Ridge National Laboratory
P&ID	Process and Information Diagram
PANDA	Passive Nachwarmeabfuehr-und Drueckabbau-Testanlage (Passive Decay Heat Removal and Depressurization Test Facility)
PANTHERS	Performance Analysis and Testing of Heat Removal Systems
PAR	Passive Autocatalytic Recombiners
PCCS	Passive Containment Cooling System
PCT	Peak Cladding Temperature
PIRT	Phenomena Identification and Ranking Tables
PSTF	Pressure Suppression Test Facility
RC&IS	Rod Control and Information System
RPV	Reactor Pressure Vessel

[2] ESBWR RAI 252

Abbreviations and Acronyms (Continued)

RWCU	Reactor Water Cleanup
SB	Small Break
SBWR	Simplified Boiling Water Reactor
S/C	Suppression Chamber (wetwell)
SDC	Shutdown Cooling
SIET	Societa Informazioni Esperienze Termoidrauliche
SLCS	Standby Liquid Control System
SPERT	Special Power-Excursion Reactor Tests
SRV	Safety/Relief Valve
SSAR	Standard Safety Analysis Report
SSLC	Safety System Logic Control
SSTF	Steam Sector Test Facility
TAPD	Test and Analysis Program Description
TCV	Turbine Control Valve
THTF	Thermal-Hydraulic Test Facility
TLTA	Two-Loop Test Apparatus
TRAC	Transient Reactor Analysis Code
TRACG	Transient Reactor Analysis Code, GE version
TT	Turbine Trip
UCB	University of California, Berkeley
VB	Vacuum Breaker
WW	Wetwell

S1.0 Introduction

S1.1 Purpose

Supplement 1 provides a discussion of the Phenomena Identification and Ranking Tables (PIRT) parameters described in Section 2 of the ESBWR Test and Analysis Program Description (TAPD) [1].

S1.2 Definition of PIRT Phenomena Listed in TAPD

This section provides definitions of phenomena considered in TAPD.

S1.3 Discussion of PIRT Phenomena and Rankings

This section provides a discussion of PIRT Phenomena and Rankings.

S1.3.1 Loss-of Coolant Accidents (Reactor Vessel and Core)

This section provides a discussion of the detailed phenomena considered for LOCA (Reactor Vessel and Core).

[3] ESBWR RAI 244: paragraph moved from end of section to front

The two-phase level in a particular region of the vessel is determined by the average void fraction below the level. Thus, these parameters are closely coupled. In the lower plenum, the void distribution [A4] is an important parameter. Towards the end of the blowdown period, the vapor generation due to flashing decreases. This will cause the mixture level to subside in the chimney. There are restrictions at the top of the core, bypass, guide tubes and the lower plenum. As the vapor flow rates decrease, the liquid will try to drain back through these restrictions in counter current flow. Occurrence of Counter Current Flow Limiting (CCFL) can cause separate two-phase levels to form in some of these regions, even though mass is held up in the chimney. However, both test data and sensitivity studies with TRACG have since shown that CCFL plays a minimal role in ESBWR LOCA transients.[4]

[4] ESBWR RAI 242

S1.3.2 Loss-of Coolant Accidents (Containment)

This section provides a discussion of the detailed phenomena considered for LOCA (Containment).

Table S1-4 serves the same purpose as Table S1-3, except for the long term containment response.

[5] ESBWR RAI 244: paragraph moved from end of section to front

S1.3.3 Transients

This section provides a detailed discussion of the phenomena considered for transients.

Important phenomena for the pressurization transients are summarized in Table S1-5. They are grouped under the broad categories (Global Parameters) of Initial Operating State, Transient Thermal Hydraulic/Neutronic Response, and Margin to Boiling Transition. The second column of Table S1-5 lists the individual parameters that affect the global parameters. At the next level, the third column lists the individual phenomena that determine the parameters in the second column.

[6] ESBWR RAI 244: paragraph moved from end of section to front

S1.3.4 Anticipated Transients Without Scram (Pressurization Transients)

This section presents a discussion of the detailed phenomena considered in ATWS (Pressurization Transients).

S1.3.5 Stability

This section provides a discussion of the detailed phenomena related stability as provided in TAPD Sections 2.2.4 and 2.3.4.

* J. March-Leuba, E.D. Blakeman, "A Mechanism for Out of Phase Power Instabilities in Boiling Water Reactors", Nuclear Science & Engineering, 107, pp. 173-179 (1991)

The dryers do not play a significant role in any of the stability evaluations. Steam Dome [Items K1, K2, K3]

S1.4 Conclusion

Based on the results of the ranking evaluation in the PIRT (Top-Down approach, TAPD Section 2) and the results of the identification of the ESBWR-unique features (Bottom Up approach, TAPD Section 3) a composite list was developed. Items ranked high were carried through for further analysis in TAPD Section 4. In addition those ranked medium in importance were also examined, but in less detail. The matrix of tests to address the identified phenomena

are shown in Section 5 of the TAPD, where the needs for any further required qualification of TRACG are also examined.

S1.6 References

[1] *ESBWR Test and Analysis Program Description*, NEDC-33079P, August 2002

[2] *SBWR Test and Analysis Program Description*, NEDC-32391P, Revision C, August 1995.

[3] Letter from Theodore R. Quay (NRC) to James E. Quinn (GE), *Staff Evaluation of General Electric's (GE's) Test and Analysis Program Description, NEDC-32391, Revision C,* July 11, 1996.

[4] *TRACG Qualification*, J.G.M. Andersen, Y.K. Cheung, C.L. Heck, L.A. Klebanov, J.C. Shaug, B.S. Shiralkar, NEDE-32176P, Revision 2, Licensing Topical Report, January 2000.

Table S1-1 Definition of PIRT Phenomena Listed in TAPD

Table S1-1 Definition of PIRT Phenomena Listed in TAPD (Continued)

Table S1-1 Definition of PIRT Phenomena Listed in TAPD (Continued)

Table S1-1 Definition of PIRT Phenomena Listed in TAPD (Continued)

Table S1-1 Definition of PIRT Phenomena Listed in TAPD (Continued)

Table S1-1 Definition of PIRT Phenomena Listed in TAPD (Continued)

PIRT Ref. No.	Phenomena from Section 2 & 3 Tables	Definition
	Reactor Vessel	
E	**Downcomer**	
E1	DC break uncovery	Applicable to a GDCS line break. As the mixture level falls to the GDCS line elevation, the break "uncovers", and the break flow changes to predominantly steam. Consequently, the depressurization rate increases after break uncovery.
E2	DC void profile/two-phase level	Downcomer void profile and two-phase level determine the driving head for natural circulation flow during normal operation and transients. The position of the two-phase level determines break uncovery (GDCS line break) and the quenching efficiency of injected water. The static head in the downcomer above the lower level measurement tap triggers various trips including scram.
E3	Cold water injection below level	Cold water injection below two-phase level includes feedwater, IC return flow, and GDCS flow. The effects considered are: condensation of voids, subcooling of downcomer and lower plenum, and determination of upstream conditions for break flow.
E4	3-D effects	Potential for asymmetries in the flow and void distribution in the downcomer because of a break in one of the GDCS lines
E5	DC heat slabs	Release of stored energy from the downcomer walls to the fluid in the downcomer. Caused by a drop in the saturation temperature of the fluid as the vessel depressurizes. The increase in the subcooling of the downcomer can also result in sensible energy transfer to the downcomer fluid. These effects are important below the elevation of the two-phase level. However, cold water injected above the level may also splash off the downcomer walls.
E6	DC flashing	Flashing of inventory in the downcomer due to depressurization. Can affect break flow if liquid is entrained.
E7	Cold water injection above level	Cold water injection above the two-phase level; includes Steamline, IC return, and GDCS flow. The effects considered are: quenching of steam, changes in downcomer inventory, and possible entrainment into the break region.
E8	DC break flow	Critical flow out of the break in the GDCS line affects downcomer and vessel inventory and depressurization. The break flow is a function of the upstream stagnation pressure and enthalpy. At low pressure,the break flow will transition to unchoked, Bernoulli flow.
E9	Shutdown cooling mixing in downcomer	Shutdown cooling suction and discharge nozzles are in the downcomer. Refers to possibility of shutdown cooling bypass of the core region.
F	**Chimney/Upper Plenum**	
F1	Chimney void distribution/two-phase level	Average void fraction in the chimney partitions and the axial distribution of voids. The void distribution is related to two-phase level in the chimney regions. The inventory in the chimney is an indicator of the margin to core uncovery.
F2	Chimney flow distribution	The flow distribution among the various chimney regions. This is determined by the distribution of channel and the bypass flow feeding the chimney region.

Table S1-1 Definition of PIRT Phenomena Listed in TAPD (Continued)

Table S1-1 Definition of PIRT Phenomena Listed in TAPD (Continued)

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Table S1-1 Definition of PIRT Phenomena Listed in TAPD (Continued)

Table S1-1 Definition of PIRT Phenomena Listed in TAPD (Continued)

Table S1-1 Definition of PIRT Phenomena Listed in TAPD (Continued)

PC8	PCCS startup with N/C	Purging of noncondensibles from the PCC unit is essential for its effective operation. Purging of noncondensibles is expected because of the driving pressure difference between the drywell and wetwell. The PCC units will purge at the beginning of the blowdown, and also after actuation of the vacuum breakers when noncondensibles are returned to the drywell.
DWB	**Drywell/Wetwell boundary**	
DWB1	DW/WW boundary leakage	Leakage of steam from the drywell to the wetwell vapor space. Controlled by the leakage characteristics. The major component of this leakage is assumed to be through the vacuum breakers.[7] Represents energy that bypasses the PCCS.
VB	**Vacuum breakers**	
VB1	Vacuum breaker mass flow	Return flow from the wetwell vapor space to the drywell as a result of vacuum breaker opening. The flow rate is determined by the frictional loss characteristics of the vacuum breaker. Opening the vacuum breaker returns noncondensibles to the drywell, which have to be purged through the PCC units.
EQ	**Equalization line**	
EQ1	Equalizing line mass flow	Flow from the suppression pool to the reactor vessel, in the event the downcomer collapsed water level falls to 1 m above the top of the core. Flow rate determined by the suppression pool static head and the equalization line frictional losses.

[7] ESBWR RAI 222

EQ2	S/P heatup due sloshing past GDCS equalizing line biased open check valve	Possibility of manometric oscillations between suppression pool and RPV dpwncomer after equalization line opens and check valve is stuck biased open. Would transfer some energy to pool.

Table S1-1 Definition of PIRT Phenomena Listed in TAPD (Continued)

PAR	**Passive Autocatalytic Recombiner**	
PAR1	PAR efficiency in hydrogen rich environment	Performance characteristics of PAR following severe accident
	System Interactions	
XC1	Interaction between IC/PCCS	Effect of steam flow split between ICS and PCCS on total heat removal by the two systems in the blowdown phase of the accident
XC2	Interaction between IC/GDCS/PCCS	Interaction between GDCS condensation and depressurization of the RPV and drywell and steam flow split between the ICS and PCCS. Affects containment pressure resonse and heat removal.
XC4	Interaction between FAPCS/PCCS	The FAPCS can be aligned to the suppression pool cooling mode after the RPV level has been restored. Pool cooling and mixing should have a beneficial effect on the wetwell pressure.
XC5	Interactions between multiple PCCS modules and units	Possible effects of flow split to PCC modules and unit on overall PCCS performances
XC6	Effect of Light noncondensible gas on DW/PCCS/WW response	Distribution of light gases such as hydrogen within the drywell and PCC condensers and effect on PCC heat removal and containment pressure response.

Table S1-1 Definition of PIRT Phenomena Listed in TAPD (Continued)

Table S1-2 a. Rationale for Important Parameters for ESBWR LOCA (Blowdown Period)

[8] ESBWR RAI 242:CCFL not important

Table S1-2 b. Rationale for Important Parameters for ESBWR LOCA (GDCS period)

[9] ESBWR RAI 242:CCFL not important

Table S1-3 Rationale for Important Parameters for Short Term Containment Pressure Response (Blowdown Period)

Table S1-4 Rationale for Important Parameters for Long Term Containment Response (GDCS & PCCS Periods)

Table S1-5 Rationale for Important Parameters for Pressurization Transients

Table S1-6 Rationale for Important Parameters for Depressurization Transients

Table S1-7 Rationale for Important Parameters for Plant Startup Transient

Table S1-8 Rationale for Important Parameters for Loss of Feedwater Heater Transient

APPENDIX B

SIGNIFICANT QUESTIONS