Panel Session: V&V and more in Nuclear Thermal-Hydraulics

F. D’Auria
M. Lanfredini

NUTHOS-12
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PREFACE

CONNECTION

NUCLEAR TECHNOLOGY & NRS \(\leftrightarrow\) SYS TH \(\leftrightarrow\) V & V

1950: NPP designed, no computers, no SYS TH
1960: Fundamental TH, computers appeared
1970: Complex TH, numerical codes appeared
1980: V & V needs, experimental Data Base available
1990: Uncertainty Methods (UM) appeared, V & V ‘finalized’ (SYS TH words)
2000: UM, V & V, Best Estimate Plus Uncertainty (BEPU) attempts
2010: Domain for BEPU

INDUSTRY & REGULATORS ACCEPTANCE NEEDED FOR BEPU
V & V ESSENTIAL
LIST OF CONTENT

1) OUTLINE OF CURRENT/ADVANCED V&V

- DOMAIN OF SIMULATION FOR SYSTEM CODES
  - Precision Objectives
  - Qualitative and Quantitative Accuracy Evaluation
- CONSIDERATION OF 116TH PHENOMENA
- SCALING PART OF V&V – RECENT FINDINGS
- INDEPENDENT ASSESSMENT & ASSESSMENT OF ASSESSMENT

IDENTIFICATION

OF KEY TOPICS

2) THE MOTIVATION FOR V&V&C

3) THE DEFINITION OF ‘C’ = CONSISTENCY

4) THE ROADMAP FOR V&V&C
1. Design of system thermal-hydraulic codes:
   - Domain of simulation
   - Precision objective
   - Attributes for safety analyses
   - Scaling requirements

2. The development of codes implies the consideration of the following elements:
   - Physical models
     Fundamental models for thermal-hydraulics
     Special thermal-hydraulic models
     Non-thermal-hydraulic systems (noticeably nuclear fuel and neutron physics)
   - Numerics
   - Code implementation
     Structure
     Programming
     Software Quality Engineering
   - Code assessment strategy within the development process
   - Code manual
   - Life cycle
     Quality Assurance
3. The following areas form the Verification:
   – Numerical algorithm and numerical solution
     Numerical scheme
     Verification matrix for numerical algorithm and solution
     Types of verification solutions
     Accuracy definition and numerical error estimation
     Qualitative
     Quantitative
     Checklist for review and inspection
   – Source code
     Tools for verification
     Portability of the code
     Review and inspection
   – Development of nodalization
4. The following areas form the Validation:
   – Physical laws and closure relations
   – Validation matrix
     Basic tests
     Separate Effect Tests
     Integral Effect Tests
     Large scale experiments
     Containment experiments
     NPP data
     Scaling
     Code-to-code comparison
   – Accuracy definition
     Qualitative
     Quantitative
   – Validation report
     Assessment of validation
   – Use of validation for uncertainty
     Sources of uncertainty
   – Sensitivity tests
   – Qualification of nodalization
     Thresholds of acceptability
   – User effect
   – User guidelines
5. Independent assessment must be connected with code maintenance and improvement:
   – Independent assessment (meaning of)
     The matrix
     Use of sensitivity analyses
     Assessment of validation
   – Maintenance (meaning of)

6. Code application in nuclear technology implies the consideration of the following topics:
   – Key applications
     Licensing and V & V
     Technology consistent independent assessment matrix
     Assessment of an individual calculation
     Documents for user qualification
   – Code application and uncertainty
OUTLINE OF CURRENT V&V

DOMAIN OF SIMULATION FOR SYS TH CODES

NPP FEATURES

NEEDS FOR THE OPERATION & DESIGN

OTHER NEEDS

THE DBA ENVELOPE

• TH PHENOMENA
• OPERATOR TRAINING
• SCALING
• USER FRIENDLY
• ETC.

ENTERING THE DIAGRAM IN THE NEXT SLIDE
OUTLINE OF CURRENT V&V

DOMAIN OF SIMULATION FOR SYS TH CODES

NEEDS

CODE FEATURES & CAPABILITIES

OUTLINE OF CURRENT V&V

DOMAIN OF SIMULATION FOR SYS TH CODES

NEEDS

CODE FEATURES & CAPABILITIES

OUTLINE OF CURRENT V&V

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OUTLINE OF CURRENT V&V

DOMAIN OF SIMULATION FOR SYS TH CODES

NEEDS

CODE FEATURES & CAPABILITIES
NOMENCLATURE & PRECISION OBJECTIVES

Nomenclature / Disciplines of Multi-physics

- B = Boron including mixing and separation.
- CH = Chemistry restricted to the zirconium-water reaction.
- FP = Fuel performance.
- GT = Gas Transport (N2, H2 and fission products) including mixing and separation.
- I&C = Instrumentation and Control including the logics.
- ME = Mechanics, e.g. dealing with the inertial behavior of rotors.
- NP = Neutron Physics.
- NVFP = Non-volatile fission products transport including mixing and separation.
- TH = Thermal-Hydraulics including conduction and radiation heat transfer.

Precision objectives

The precision objectives shall be fixed in relation to each of the listed disciplines, making reference to:

- Steady state.
- Transient at qualitative level.
- Transient at quantitative level.
OUTLINE OF CURRENT V&V

PRECISION OBJECTIVES

Acceptance criteria for Nodalization

Quantitative Accuracy – Application of FFTBM

<table>
<thead>
<tr>
<th>QUANTITY</th>
<th>ACCEPTABLE ERROR (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Primary circuit volume</td>
<td>1 %</td>
</tr>
<tr>
<td>2. Secondary circuit volume</td>
<td>2 %</td>
</tr>
<tr>
<td>3. Non-active structures heat transfer area (overall)</td>
<td>10 %</td>
</tr>
<tr>
<td>4. Active structures heat transfer area (overall)</td>
<td>0.1 %</td>
</tr>
<tr>
<td>5. Non-active structures heat transfer volume (overall)</td>
<td>14 %</td>
</tr>
<tr>
<td>6. Active structures heat transfer volume (overall)</td>
<td>0.2 %</td>
</tr>
<tr>
<td>7. Volume vs. height curve (i.e. “local” primary and secondary circuit volume)</td>
<td>10 %</td>
</tr>
<tr>
<td>8. Component relative elevation</td>
<td>0.01 m</td>
</tr>
<tr>
<td>9. Axial and radial power distribution (**)</td>
<td>1 %</td>
</tr>
<tr>
<td>10. Flow area of components like valves, pumps orifices</td>
<td>1 %</td>
</tr>
<tr>
<td>11. Generic flow area</td>
<td>10 %</td>
</tr>
<tr>
<td>12. Primary circuit power balance</td>
<td>2 %</td>
</tr>
<tr>
<td>13. Secondary circuit power balance</td>
<td>2 %</td>
</tr>
<tr>
<td>14. Absolute pressure (PRZ, SG, ACC)</td>
<td>0.1 %</td>
</tr>
<tr>
<td>15. Fluid temperature</td>
<td>0.5 % (**)</td>
</tr>
<tr>
<td>16. Rod surface temperature</td>
<td>10 K</td>
</tr>
<tr>
<td>17. Pump velocity</td>
<td>1 %</td>
</tr>
<tr>
<td>18. Heat losses</td>
<td>10 %</td>
</tr>
<tr>
<td>19. Local pressure drops</td>
<td>10 % (*)</td>
</tr>
<tr>
<td>20. Mass inventory in primary circuit</td>
<td>2 % (***)</td>
</tr>
<tr>
<td>21. Mass inventory in secondary circuit</td>
<td>5 % (*)</td>
</tr>
<tr>
<td>22. Flow rates (primary and secondary circuit)</td>
<td>2 %</td>
</tr>
<tr>
<td>23. Bypass mass flow rates</td>
<td>2 %</td>
</tr>
<tr>
<td>24. Presurizer level (collapsed)</td>
<td>0.05 ft</td>
</tr>
<tr>
<td>25. Secondary side or downcomer level</td>
<td>0.1 m</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Phase (a)</th>
<th>BL-34</th>
<th>BL-44</th>
<th>SB-03</th>
<th>SB-04</th>
<th>6.2-TC</th>
<th>CL-21</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pressurizer emptying</td>
<td>E</td>
<td>E</td>
<td>R</td>
<td>R</td>
<td>R</td>
<td>R</td>
</tr>
<tr>
<td>Maximum break flowrate/initial flowrate</td>
<td>R</td>
<td>R</td>
<td>R</td>
<td>R</td>
<td>E</td>
<td>R</td>
</tr>
<tr>
<td>Average specific break flowrate during phase (a)</td>
<td>R</td>
<td>R</td>
<td>R</td>
<td>R</td>
<td>E</td>
<td>R</td>
</tr>
<tr>
<td>First dry out duration</td>
<td>M</td>
<td>M</td>
<td>M</td>
<td>M</td>
<td>M</td>
<td>M</td>
</tr>
<tr>
<td>Period for dry out starting at bottom level</td>
<td>E</td>
<td>E</td>
<td>E</td>
<td>E</td>
<td>E</td>
<td>E</td>
</tr>
<tr>
<td>Period for dry out starting at middle level</td>
<td>M</td>
<td>E</td>
<td>M</td>
<td>E</td>
<td>M</td>
<td>M</td>
</tr>
<tr>
<td>Period for dry out starting at high level</td>
<td>M</td>
<td>M</td>
<td>M</td>
<td>E</td>
<td>M</td>
<td>M</td>
</tr>
<tr>
<td>Pump stop or pump velocity</td>
<td>E</td>
<td>E</td>
<td>E</td>
<td>E</td>
<td>E</td>
<td>E</td>
</tr>
</tbody>
</table>

ACCEPTABILITY DOMAIN
Results related to the “acceptability of input deck” are reported in the same diagram as results of “acceptability of calculation results”.

OUTLINE OF CURRENT V&V

PRECISION OBJECTIVES – Nodalization & Calculation Acceptance
OUTLINE OF CURRENT V&V

CONSIDERATION OF 116 PHENOMENA

Thermal-hydraulic phenomena for water cooled nuclear reactors
N. Aksan, F. D'Auria, H. Glaeser

CROSS-LINK WITH
ACCIDENT SCENARIOS
PARAMETERS

Excerpt from list of 116

<table>
<thead>
<tr>
<th>Phenomenon</th>
<th>New Reactors</th>
<th>Also containment</th>
</tr>
</thead>
<tbody>
<tr>
<td>A-11-NC</td>
<td>NC R/P and containment &amp; various system configurations</td>
<td>SETF</td>
</tr>
<tr>
<td>S-42-NOC</td>
<td>Natural convection and H2 distribution</td>
<td>SETF</td>
</tr>
<tr>
<td>S-43-NCG</td>
<td>Non condensible gas effect including condensation HT in RCS</td>
<td>SETF</td>
</tr>
<tr>
<td>S-44-PEC</td>
<td>Nuclear fuel behavior</td>
<td>SETF</td>
</tr>
<tr>
<td>S-45-PSB</td>
<td>Nuclear thermal-hydraulics feedback and spatial effect (see also S-29-NTF2)</td>
<td>ITF</td>
</tr>
<tr>
<td>S-46-PS1</td>
<td>Nuclear thermal-hydraulics instabilities</td>
<td>SETF</td>
</tr>
<tr>
<td>S-47-PS2</td>
<td>Parallel channel effects and instabilities</td>
<td>SETF</td>
</tr>
<tr>
<td>S-48-PS3</td>
<td>Phase separation/vertical flow with and w/o mixture level-Core</td>
<td>SETF</td>
</tr>
<tr>
<td>S-49-QFF</td>
<td>Phase separation/vertical flow with and w/o mixture level-Downcomer</td>
<td>SETF</td>
</tr>
<tr>
<td>S-50-QFF</td>
<td>Pool formation in UP</td>
<td>ITF</td>
</tr>
<tr>
<td>S-51-SEP</td>
<td>Pressure drops at geometric discontinuities, including containment</td>
<td>ITF</td>
</tr>
<tr>
<td>S-52-SPR</td>
<td>Pressure-temperature increase &amp; boiling due to energy and mass input</td>
<td>ITF</td>
</tr>
<tr>
<td>S-53-SPR</td>
<td>PRZ thermal-hydraulics</td>
<td>ITF</td>
</tr>
<tr>
<td>S-54-SPR</td>
<td>PRZ thermal-hydraulics</td>
<td>ITF</td>
</tr>
<tr>
<td>S-55-SPR</td>
<td>OF propagation/wet-Fuel rods</td>
<td>SETF</td>
</tr>
<tr>
<td>S-56-SPR</td>
<td>OF propagation/wet-Channel walls, Water rods</td>
<td>SETF</td>
</tr>
<tr>
<td>S-57-SPR</td>
<td>Refill including loop refill in PWR-O</td>
<td>ITF</td>
</tr>
<tr>
<td>S-58-SPR</td>
<td>Reflood</td>
<td>ITF</td>
</tr>
<tr>
<td>S-59-SPR</td>
<td>Return to Nucleate Boiling (RNB)</td>
<td>ITF</td>
</tr>
<tr>
<td>S-60-SPR</td>
<td>Separator behavior (* flooding, steam penetration, liquid carry-over)</td>
<td>SETF</td>
</tr>
<tr>
<td>S-61-SPR</td>
<td>SG siphon draining (SG interaction with ESF, including gravity driven)</td>
<td>ITF</td>
</tr>
<tr>
<td>S-62-SPR</td>
<td>Spray effects-Containment (added T-HP)</td>
<td>SETF</td>
</tr>
<tr>
<td>S-63-SPR</td>
<td>Spray effects-Core (including cooling and distribution)</td>
<td>SETF</td>
</tr>
</tbody>
</table>

journal homepage: www.elsevier.com/locate/nuengdes
OUTLINE OF CURRENT V&V

SCALING

HIERARCHY & KNOWLEDGE MANAGEMENT

OECD/NEA/CSNI S-SOAR – 2017

Scaling Applications

Category 3 Approaches
- Power/Volume, H2TS, FSA, Ishii, etc.
- SYS TH codes for alternative confirmation

Category 2 Requirements
- CSAU, RG-1.103 – Requirements
- SYS TH Codes V & V, UMAE, CIAU, GRS
- BEMUSE – Other requirements

Category 1 Technological bases
- NPP Data & Plant Analysis Data
- J NED 1998 Special Issue
- CSNI CCVM OF ITF & SETF
- USNRC Compendium
- CSNI SOAR on TECC
- ITF & SETF Design, Data and Data Analysis, CT, 2D/3D tests, etc.

‘BRIDGES’ & ACHIEVEMENTS

Operational Transients
- Full Scale (NPP, TMI-2)
- LOFT
- UPTF
- CT-2
- CT-1
- Similar Tests

Conduction HT
- HTC rod-to-fluid
- Sub-channel-mixing

Established Similitude

Code-Nodalization Qualification & Uncertainty Evaluation

Nomenclature, Symbols & Notes
- CT = Counterpart Test
- HT = Heat Transfer
- HTC = Heat Transfer Coefficient
- E = Scaling Envelope
- N = No further scaling (theory) need
- = 'straightforward' Scaling Connection
- = Scaling Issue considered
- A wide variety of operational transients are available to ‘bypass’ the Scaling Issue.
- A few accident scenarios, other than TMI-2, are available to ‘bypass’ the Scaling Issue.
- Neutron Physics is not part of the current picture. However, it does not put a border to present conclusions.
OUTLINE OF CURRENT V&V

INDEPENDENT ASSESSMENT & ASSESSMENT OF ASSESSMENT

QUALIFIED CODE USER / USER GROUP

(demonstration of)
INDEPENDENT ASSESSMENT

SENIOR EXPERT
(not involved with calculation preparation-outcomes)

(demonstration of)
ASSESSMENT OF ASSESSMENT

<table>
<thead>
<tr>
<th>No</th>
<th>Type</th>
<th>Concerned NPP</th>
<th>Concerned phenomenon or DBA</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Basic</td>
<td>-</td>
<td>Bottle emptying</td>
<td>To test code features</td>
</tr>
<tr>
<td>2</td>
<td></td>
<td>U-tube manometer</td>
<td>U-tube manometer</td>
<td>To test code features and dependency of results upon boundary conditions</td>
</tr>
<tr>
<td>3</td>
<td></td>
<td></td>
<td>Pressure drops in two phase flow</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>SET</td>
<td></td>
<td>TPCF</td>
<td>Key phenomenon for DBA Analysis</td>
</tr>
<tr>
<td>5</td>
<td></td>
<td></td>
<td>Transient CHF</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>ITF</td>
<td>PWR</td>
<td></td>
<td>Counterpart Test, to address the scaling issue</td>
</tr>
<tr>
<td>7</td>
<td></td>
<td></td>
<td></td>
<td>To perform Kv-scaled calculation</td>
</tr>
</tbody>
</table>

CODE AREAS

PHENOMENA RTA PARAMETER RANGES

DBA framework

BASIC TEST SET ITF TESTS NPP TESTS

RESULTS & DOCUMENTATION

Each item of code structure is relevant

Accuracy evaluation with acceptability thresholds

Assessment of validation
OUTLINE OF CURRENT V&V

(RESULTING) ATTRIBUTE FOR A SYS TH CODE (unchanged in 40+ years)

Component
- Pump
- Separator
- Etc.

Special Models

Thermal-hydraulics
- ‘K’
- TPCF
- CCFL
- Etc.

Chemistry

Boron & Gas Transport

State eqs.

Material properties

Constitutive eqs.

Fluid-wall

Interfacial

Fluid

Fuel

[FLUID DOM.]

TH BALANCE EQS.

[STATE EQS.]

Mechanics

[FOURIER DOM.]

Radiation HT

HTC

[QUANT DOM.]

NK DIFFUSION EQS.

NODALIZATION

BIC

I & C

NPP

CV + J approach
Averaging

- τi
- flow regimes
- virtual mass
- etc.

- HT surface
- friction

... Plus Qualification
... Plus Uncertainty
OUTLINE OF CURRENT V&V

SEVERAL INTERCONNECTED TOPICS

- NUMERICS
- COMPUTER-COMpiler ISSUES
- USER CONVENIENCES
- QUALITY ASSURANCE
- LIFE CYCLE
- UNCERTAINTY
- SCALING

- USER QUALIFICATION
- INPUT - OUTPUT
- USER EFFECT

MULTI-DISCIPLINARY
MULTI-PHYSICS
MULTI-SCALE
MULTI-ACTORS

CONTEXT
1) Accuracy of NTH models lags behind technological needs

Thermal-hydraulic model capabilities are found to lag behind industry needs, requiring innovative ideas and investigations; the following log-frame to be considered:

V&V Capability ⇔ Development and Qualification.

**DESIGN LEVEL**

*INDUSTRY PROPOSAL FOR NEW RESEARCHES*
(e.g. spacer grids, CHF margins)

**SAFETY LEVEL**

*NC FLOWRATE*
(e.g. Max NC flow, Conditions for flow reversal in SG U-tubes)

**PRIORITIZATION OF RESEARCH NEEDED**
(to confirm adequacy of research strategy and needed V&V)

*NOT DONE! (method available)*
THE MOTIVATION FOR V & V & C

2) Inadequate experimental database (EXP-DB) - 1 of 2

(showing) NARROW PARAMETER RANGES FOR VALIDATION

Trajectory during transient application

REGION known to be outside the validation range

REGION where model is expected to be validated or validation is needed

actual validation regions
THE MOTIVATION FOR V & V & C

2) Inadequate experimental database (EXP-DB) - 2 of 2

CSNI SETF & ITF EXP-DB COVERS (<) < 1% parameter ranges / combinations expected in DBA of WCNR ⇒ Situation may be worse looking at 116 TH phenomena.

EXP DB ESSENTIAL FOR VALIDATION, BUT NOT ENOUGH

SURROGATE OF EXPERIMENTS NEEDED

3) Inadequate V & V role: (a) - TPCF

DATA OWNED BY FONESYS NETWORK

1980

2015
THE MOTIVATION FOR V & V & C

3) Inadequate V & V role: (b) – CHF & FILM BOILING

CURRENT V & V
NOT ENOUGH TO IMPROVE MODELING CAPABILITIES

NEED TO ENLARGE
THE SCOPE FOR V&V

DATA OWNED BY FONESYS NETWORK
The rudimentary and broad definition for consistency is:

‘Consistency is an activity connected with the development and the qualification of numerical codes which covers topics not considered by current V&V’.

A detailed definition is expected to cover the above issues, to take into account of (fundamental) physical laws even in the absence of experimental evidence, to provide a hint for the development of computational tools and to not contradict the current V&V (rather being complementary to the existing procedures):

‘Consistency aims at filling gaps of V&V in nuclear thermal-hydraulics, with focus:

a) to connect the modeling features and the technological needs,

b) to take into account of the limitations of the experimental database mainly in terms of the space covered by parameter ranges,

c) to streamline the conditions for developing improved capability models’.
THE DEFINITION OF ‘C’ = CONSISTENCY
The Roadmap for V&V&C

Step I – **THE ELEMENTS** (consistent geometry and material properties parameter ranges)

Step II – **THE LOGFRAME** (cross linking phenomena and models)

Step III – **THE REQUIREMENTS** (consistency requirements for models)

I) THE ELEMENTS
CLASSIFYING SSC FOR CORE, RPV, PS, SS, BOP, AND CONTAINMENT,
(including materials)
IDENTIFYING/CHARACTERIZING N (> 100)

II) THE LOGFRAME
N (geometry-material) ELEMENTS
116 TH PHENOMENA
M (a few dozen) MODELS
L (a couple dozen) PARAMETERS
CROSSSLINKING N-116-M-L

III) REQUIREMENTS
.... NEXT SLIDE ....
Illa – General requirements (selected)

Any model should be applicable inside the resulting parameters space, i.e. inside and outside the range of validation in relation to which experimental data exist. Outside the range of validation, model predictions should be physically sound (according to the best available information).

Pressure drops at GD for 1 and 2-phase: fluid velocities (from zero to values corresponding to TPCF or to sound speed in both directions) and void fraction (from zero to one) at the minimum section should be independent parameters; the generation of cavitation conditions should be detected (e.g. as a function of subcooling) where necessary.

Each phenomenon shall have at least one associated model. Special models and models forming the set of constitutive equations can be distinguished.

A study of each mathematical function (M-Models) must be performed checking for peaks, valleys and singular points (including cliff-edge effects and\or conditions for bifurcations); the study shall include the derivative(s) of the function, e.g. $\frac{\partial (output\ quantity)}{\partial (input\ quantity)}$. Continuity shall be demonstrated or discontinuities justified.

Each model shall be checked for zero and negative fluid velocities, different liquid and steam velocities, the full range of pressure and temperature (etc.).

Acceptability criteria, shall be established in relation to each requirement.
### THE REQUIREMENTS FOR [V&V&C]

#### IIIb – Requirements for individual TH phenomena (one example)

<table>
<thead>
<tr>
<th>Topic / Parameters</th>
<th>Activity</th>
<th>Requirements</th>
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</thead>
<tbody>
<tr>
<td>Systematic calculations, rows 1-11, varying upstream pressure ( (p_0) ) and void ( (\alpha) ), rows 12-13, varying local pressure drop at pipe inlet, to derive:</td>
<td></td>
<td>A) Demonstrate rate continuity of functions, derivatives, etc. (Step IIIa, requirement 5.4)</td>
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<td></td>
<td>curves of ( w_g, w_f ) and ( S ) at CS</td>
<td>B) Justify differences related to the condition ( S=1 )</td>
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<tr>
<td>1 Liquid and steam velocities ( (w_g, w_f) ) and Slip ratio ( (S) )</td>
<td></td>
<td>C) At critical pressure, ( S ) must be unity</td>
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<td>2 Supersonic flow downstream the CS</td>
<td>values of ( w_f ) and ( w_g ) in supersonic conditions</td>
<td>D) Derive and explain differences between ( w_g, w_f ) and sound speed.</td>
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<td>3 Energy transfer across the CS</td>
<td>kinetic and thermal energy values</td>
<td>E) This must be computed by the model, together with return to subsonic flow.</td>
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<td>4 End of “critical conditions” at CS</td>
<td>occurrence of criticality conditions at CS</td>
<td>F) Thermal plus kinetic energy at pipe inlet must be consistent at pipe outlet</td>
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<tr>
<td>5 Derivative ( \frac{\vartheta (p_0-p_{co})}{\vartheta (TPCF)} )</td>
<td>derivative in first column</td>
<td>G) Demonstrate that non-critical flowrate ( \geq ) critical flowrate (TPCF)</td>
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<tr>
<td>6 Model a reservoir and a containment–blowdown analysis (isolated-ideal system, no structures)</td>
<td>entropy of the ‘isolated system’</td>
<td>H) Demonstrate that if containment pressure ( (p_{co}) &gt; p_{cr} ), non-critical flowrate occurs</td>
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<td>7 Cavitation at pipe inlet</td>
<td>pressure along the pipe</td>
<td>I) Demonstrate continuity (or explain discontinuities)</td>
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<td>8</td>
<td></td>
<td>J) Demonstrate the total entropy increase in the isolated system</td>
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<tr>
<td>9</td>
<td></td>
<td>K) Demonstrate peak pressure in containment not depending upon TPCF</td>
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<tr>
<td>10</td>
<td></td>
<td>L) Demonstrate dependency of TPCF upon subcooling in reservoir</td>
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<tr>
<td>11</td>
<td></td>
<td>M) Demonstrate the possibility of occurrence of TPCF at pipe inlet</td>
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</table>
CONCLUSIONS (advanced V&V)

• V & V TARGETS DERIVED FROM CODE DEVELOPMENT, NPP FEATURES & DBA ENVELOPE

• THE NODALIZATION IS A TARGET FOR V & V AND A SOURCE OF ERRORS

• ADDRESS THE SCALING ISSUE IS PART OF V & V

• CONNECT INPUT & OUTPUT ERRORS AND ERROR ACCEPTABILITY

• DISTINGUISH, WITHIN THE V & V PROCESS, BETWEEN SENSITIVITY AND UNCERTAINTY AND CONSIDER BOTH

• RECOGNIZE THE NEED OF QUALIFIED USERS FOR V & V, THEN ‘INDEPENDENT ASSESSMENT’ AND ‘ASSESSMENT OF ASSESSMENT’
CONCLUSIONS (V&V&C)

The current V&V proved inadequate for model improvement & the supporting experimental DB for validation covers only a small portion of the parameters space characterizing NPP nominal and transient conditions.

V&V&C is a (large) human-and-financial resource-consuming approach.

Checking the physical validity of the results in a parameter space where experimental data are not available, creating crosslink matrices involving parameters, phenomena, NPP components and models and imposing conditions to the mathematical formulation of models, can be used for a snapshot characterization of the ‘C’ field.

‘C’ covers both Verification and Validation. V&V&C will have a role in model development while V&V only proves model capabilities.

The change from V&V to V&V&C appears an epochal change in the area of code development and validation,
MESSAGE

V&V&C IS NOT A TECHNOLOGY BY ITSELF

V&V&C MAY REVEAL AS A MULTIDISCIPLINARY TASK

V&V&C MUST BE ADAPTED TO ANY TECHNOLOGY