University of Pisa
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Nuclear Research Group in San Piero a Grado (Pisa)- Italy

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

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*NUTHOS-12*

*12th International Topical Meeting on Nuclear Reactor Thermal-Hydraulics*

*Qingdao (PRC) - Oct. 14-18, 2018*

# PREFACE

**CONNECTION**

**NUCLEAR TECHNOLOGY & NRS ←→ SYS TH ← → 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

IDENTIFICATION + OF KEY TOPICS

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

## 2) THE MOTIVATION FOR V&V&C

## 3) THE DEFINITION OF 'C' = CONSISTENCY

## 4) THE ROADMAP FOR V&V&C

# OUTLINE OF CURRENT V&V

## IDENTIFICATION OF KEY TOPICS 1 of 4

**Unpublished IAEA report**

**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**

# OUTLINE OF CURRENT V&V

## IDENTIFICATION OF KEY TOPICS 2 of 4

**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**

**Unpublished IAEA report**

# OUTLINE OF CURRENT V&V

## IDENTIFICATION OF KEY TOPICS 3 of 4

Unpublished IAEA report

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

# OUTLINE OF CURRENT V&V

## IDENTIFICATION OF KEY TOPICS 4 of 4

**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**

**Unpublished IAEA report**

# OUTLINE OF CURRENT V&V

**DOMAIN OF SIMULATION FOR SYS TH CODES**

**NPP FEATURES**

**OTHER NEEDS**

**NEEDS FOR THE OPERATION & DESIGN**

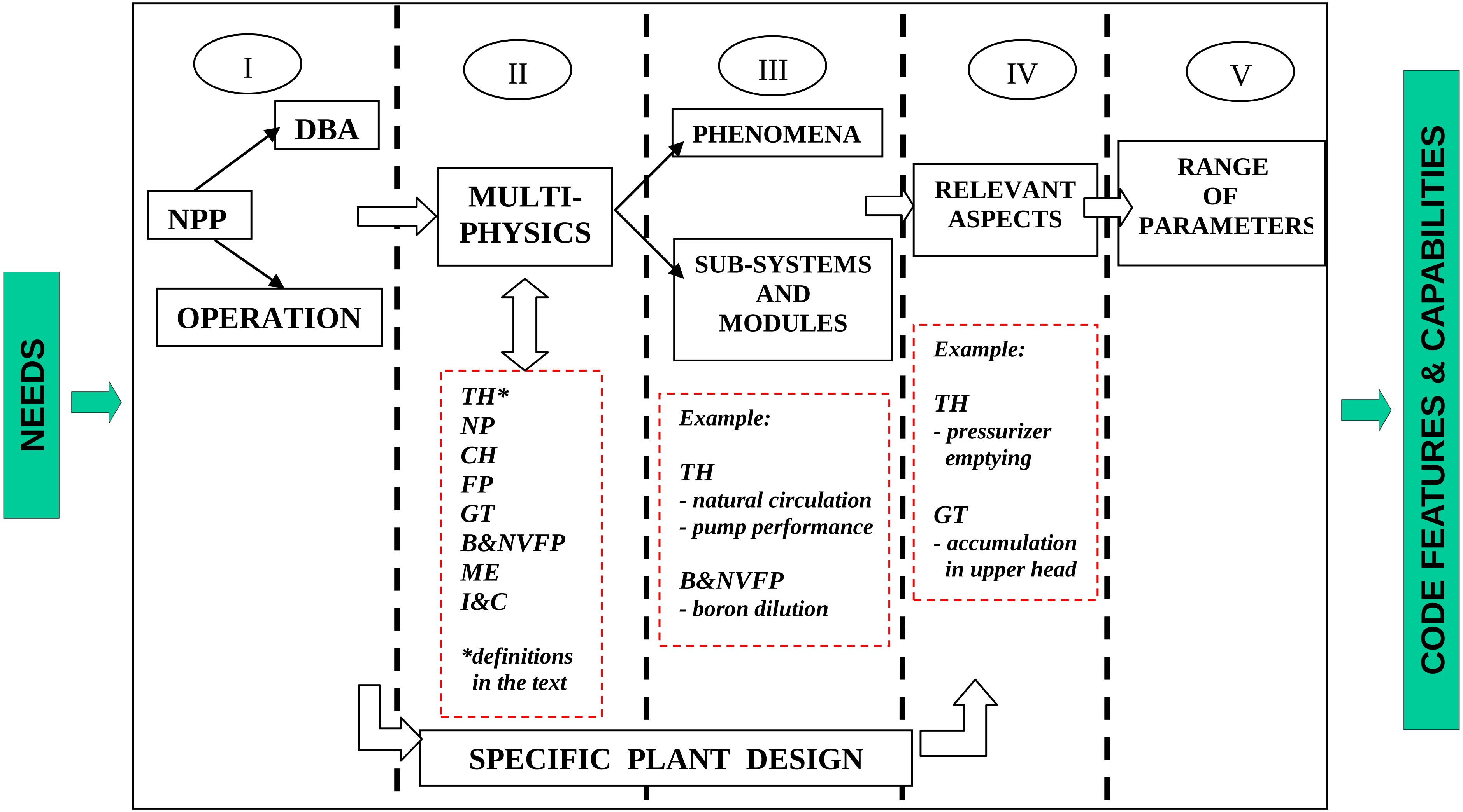
**THE DBA ENVELOPE**

- 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




*Nomenclature in next page*

# OUTLINE OF CURRENT V&V

## 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

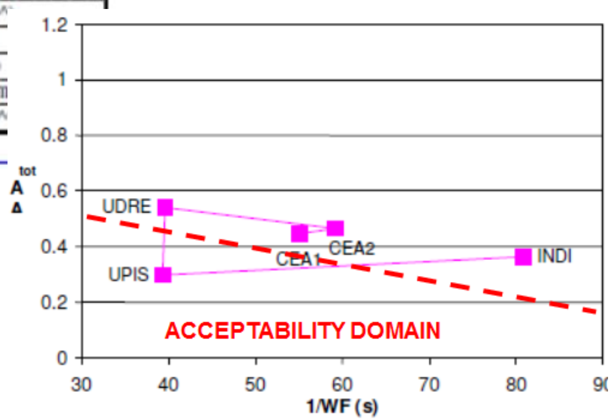
## PRECISION OBJECTIVES

### *Acceptance criteria for Nodalization*

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

### *Qualitative Accuracy*

| | | BL-34 | BL-44 | SB-03 | SB-04 | 6.2-TC | CL-21 |
|---|---|---|---|---|---|---|---|
| Phase (a) Subcooled blowdown and first core dry out rewetting | Pressurizer emptying | E | E | R | R | R | R |
| | Maximum break flowrate/initial loop flowrate | R | R | R | R | E | R |
| | Average specific break flowrate during phase (a) | R | R | R | R | E | R |
| | First dry out duration | M | M | M | M | M | M |
| | Period for dry out starting at bottom level | E | E | E | E | E | E |
| | Period for dry out starting at middle level | M | E | M | E | M | M |
| | Period for dry out starting at high level | M | M | M | E | M | M |
| | Pump stop or pump velocity | E | E | E | E | E | - |



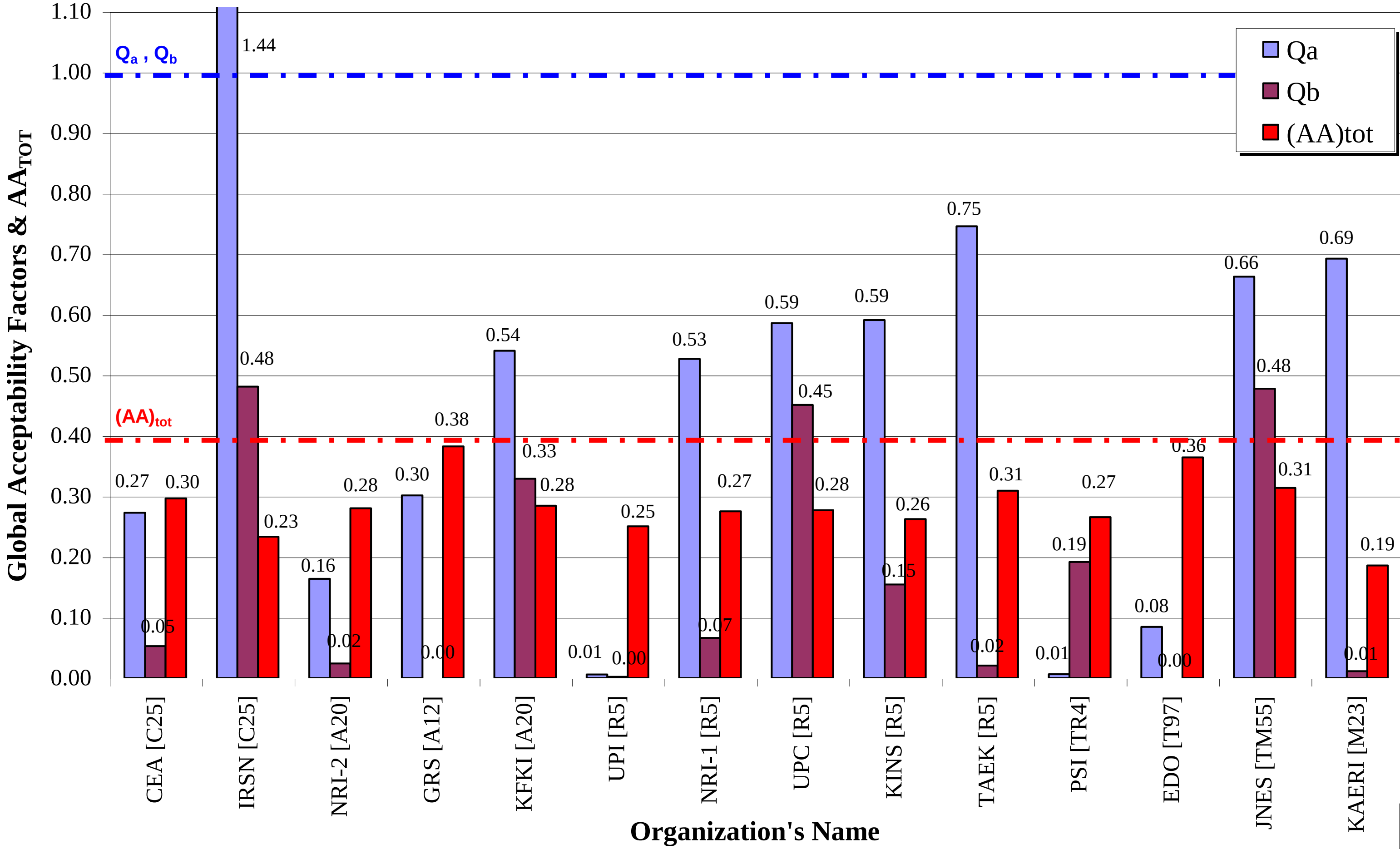

### *Quantitative Accuracy – Application of FFTBM*

| ID | Participant/Country/Code | NV | Time interval of analysis | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | 0-3000 s | | 0-6000 s | | 0-8000 s | |
| | | | $I/WF_{tot}$ | $AA_{tot}$ | $I/WF_{tot}$ | $AA_{tot}$ | $I/WF_{tot}$ | $AA_{tot}$ |
| 1 | ZFK Dresden, Germany, R5/M2 | 25 | 9.2 | 0.30 | * | * | * | * |
| 2 | KINS, Korea, R5/M3 | 25 | 10.0 | 0.68 | * | * | * | * |
| 3 | LTKK, Finland, CATH. 2 V1.2(31.) | 25 | 9.4 | 0.62 | * | * | * | * |
| 4 | Kurchatov Institute, Russia, R5/M3 | 25 | 9.7 | 0.40 | * | * | * | * |
| 5 | CIAE Beijing, China, R5/M2 | 25 | 8.8 | 0.31 | * | * | * | * |
| 6 | JINS, Japan, R5/M2 | 24 | 8.6 | 0.40 | * | * | * | * |
| 7 | JAERI, Japan, CATH. 2 V1.2(31.) | 22 | 8.5 | 0.47 | * | * | * | * |
| 8 | Studvisk Nuclear, Sweden, R5/M3 | 25 | 8.4 | 0.25 | 10.5 | 0.26 | * | * |
| 9 | NNC, England, NOTRUMP | 24 | 7.3 | 0.51 | 12.3 | 0.51 | * | * |
| 10 | Kurchatov Institute, Russia, R5/M2 | 25 | 9.4 | 0.46 | 14.9 | 0.60 | * | * |
| 11 | JAERI, Japan, CATH. 2 V1.2(21.) | 22 | 8.5 | 0.47 | 11.1 | 0.33 | * | * |
| 12 | Paul Scherrer, Switzerland, R5/M2 | 25 | 10.0 | 0.50 | 14.3 | 0.39 | * | * |
| 13 | GRS, Germany, ATHLET M1.E | 25 | 8.4 | 0.39 | 10.4 | 0.36 | * | * |
| 14 | Tractabel, Belgium, R5/M2 | 25 | 8.8 | 0.41 | 14.0 | 0.44 | * | * |
| 15 | UKAEA, England, R5/M2 | 25 | 8.6 | 0.27 | 11.5 | 0.29 | * | * |
| 16 | VTT, Finland, R5/M3 | 25 | 9.7 | 0.38 | 11.5 | 0.33 | 10.9 | 0.39 |
| 17 | Texas AMU, USA, R5/M3 | 25 | 9.6 | 0.39 | 12.0 | 0.49 | 14.2 | 0.44 |
| 18 | UKAEA, England, R5/M3 | 25 | 8.6 | 0.35 | 10.6 | 0.30 | 10.8 | 0.30 |
| 19 | KAERI, Korea, CATH. 2 V1.2(21.) | 23 | 8.1 | 0.49 | 11.5 | 0.41 | 11.6 | 0.42 |
| 20 | IPEN/CNEN, Brazil, TRAC/PF1 | 22 | 8.2 | 0.35 | 12.0 | 0.35 | 10.8 | 0.40 |
| 21 | DCMN/ENEA, Italy – Croatia, R5/M2 | 22 | 8.0 | 0.36 | 12.6 | 0.36 | 12.5 | 0.38 |
| 22 | AEKI, Hungary, R5/M2 | 25 | 10.0 | 0.52 | 15.8 | 0.55 | 14.1 | 0.55 |
| 23 | Jožef Stefan Institute, Slovenia, R5/M3 | 25 | 8.4 | 0.38 | 14.8 | 0.40 | 13.8 | 0.39 |
| 24 | Jožef Stefan Institute, Slovenia, R5/M2 | 25 | 8.4 | 0.39 | 11.9 | 0.55 | 14.9 | 0.44 |
| 25 | NPPRI, Slovakia, R5/M2 | 22 | 9.1 | 0.40 | 10.6 | 0.56 | 9.9 | 0.64 |

# OUTLINE OF CURRENT V&V

## PRECISION OBJECTIVES – *Nodalization & Calculation Acceptance*

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

## CONSIDERATION OF 116 PHENOMENA

Nuclear Engineering and Design 330 (2018) 166–186

Contents lists available at ScienceDirect

Nuclear Engineering and Design

journal homepage: www.elsevier.com/locate/nucengdes

ELSEVIER

### Thermal-hydraulic phenomena for water cooled nuclear reactors

N. Aksan[a], F. D'Auria[b,*], H. Glaeser[c]

***Excerpt from list of 116***

**CROSS-LINK WITH**

**ACCIDENT SCENARIOS**

**PARAMETERS**

| | | | | |
|---|---|---|---|---|
| I-15-NC6 | NC with horizontal SG | | PWR-V | |
| A-11-NC | NC RPV and containment & various system configurations | New Reactors | | Also containment |
| S-42-NC0-c | Natural convection and H2 distribution | SETF | | Inside containment |
| S-43-NCG | Non condensable gas effect including condensation HT in RCS | SETF | PWR | Also ITF |
| | Nuclear fuel behavior | SETF/ITF | | See I-29-NTF2 |
| I-16-NTF1 | Nuclear thermal-hydraulics feedback and spatial effect (see also I-29-NTF2) | ITF | BWR | Also RBMK, ABWR, etc. |
| | Nuclear thermal-hydraulics instabilities | ITF | BWR | See I-16 and S-44 |
| S-44-PCEI | Parallel channel effects and instabilities PCEI | SETF | BWR | |
| S-45-PSB | Phase separation at branches (including effect on TPCF) | SETF | All | Also ITF (T-branches) |
| S-46-PS1 | Phase separation/vertical flow with and w/o mixture level-Core | SETF | | Also ITF |
| S-47-PS2 | Phase separation/vertical flow with and w/o mixture level-Downcomer | | | |
| S-48-PS3 | Phase separation/vertical flow with and w/o mixture level-Pipes & Plena | | | |
| I-17-PFU | Pool formation in UP | ITF | PWR | See also S-8-CCF6 |
| B-7-PD-c | Pressure drops at geometric discontinuities, including containment | Basic | N/A | Also New Reactors |
| B-8-PW | Pressure wave propagation including CIWH | Basic | | |
| I-18-PRB | Pressure-temperature increase & boiling due to energy and mass input | ITF | PW/BWR | Containment & Shutdown |
| I-19-PRZ | PRZ thermal-hydraulics | ITF | PWR | |
| S-49-QF1 | QF propagation/rewet-Fuel rods | SETF | PWR/BWR | |
| S-50-QF2 | QF propagation/rewet-Channel walls, Water rods | | BWR | |
| I-20-RF | Refill including loop refill in PWR-O | ITF | PWR/BWR | PHW rather than PH |
| I-21-RE | Reflood | | | |
| I-22-RCM | Reflux condenser mode and CCFL | ITF | PWR | |
| | Return to Nucleate Boiling (RNB) | | | See Reflood & QF |
| S-51-SEP | Separator behavior (&* flooding, steam penetration, liquid carry-over) | SETF | PWR/BWR | *Mainly for BWR |
| I-23-SIP | SG siphon draining (SG interaction with ESF, including gravity driven) | ITF | PWR | Shutdown conditions |
| S-63-SPR-c | Spray effects-Containment (added T-HP) | SETF | All | |
| S-52-SPR1 | Spray effects-Core (including cooling and distribution) | SETF | BWR | |
| S-53-SPR2 | Spray effects-OTSG SG | | PWR-O | |

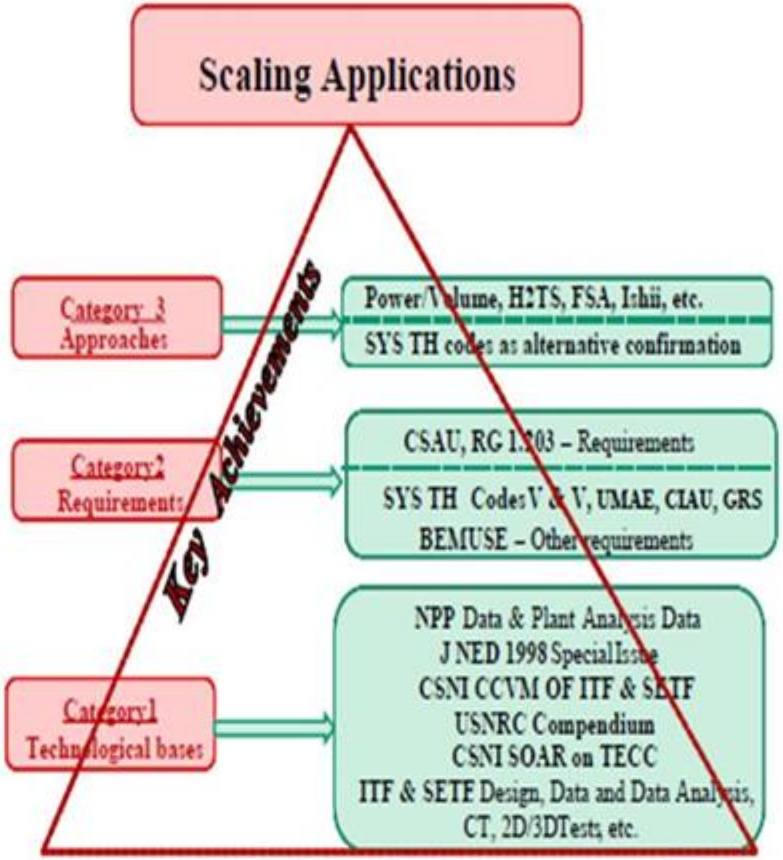
# OUTLINE OF CURRENT V&V

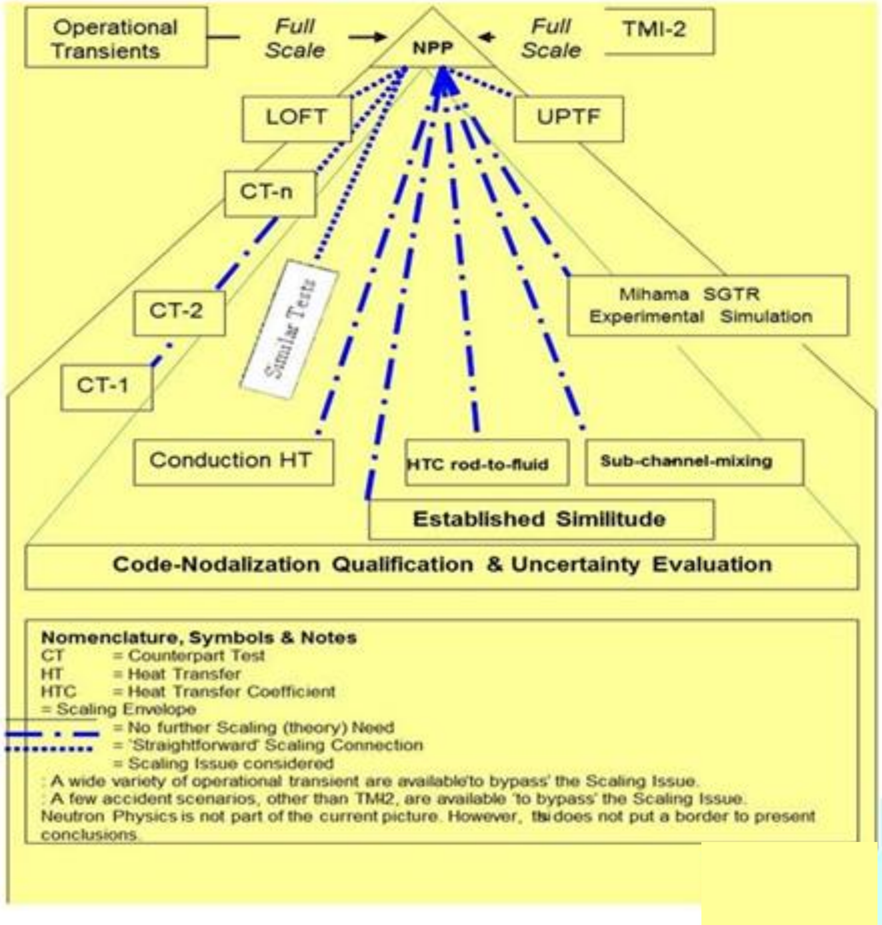
## SCALING

HIERARCHY & KNOWLEDGE MANAGEMENT

'BRIDGES' & ACHIEVEMENTS

OECD/NEA/CSNI S-SOAR – 2017



# OUTLINE OF CURRENT V&V

## INDEPENDENT ASSESSMENT & ASSESSMENT OF ASSESSMENT

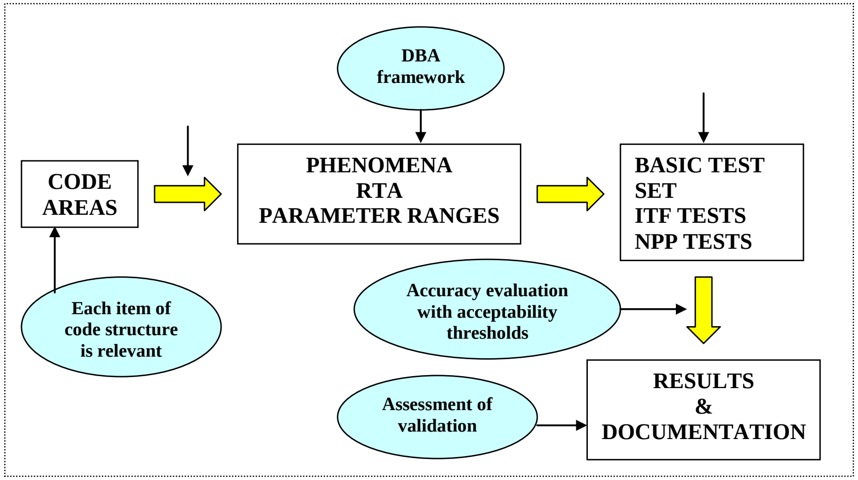
***QUALIFIED CODE USER / USER GROUP***

*(demonstration of)*
***INDEPENDENT ASSESSMENT***

***SENIOR EXPERT***
*(not involved with calculation preparation-outcomes)*

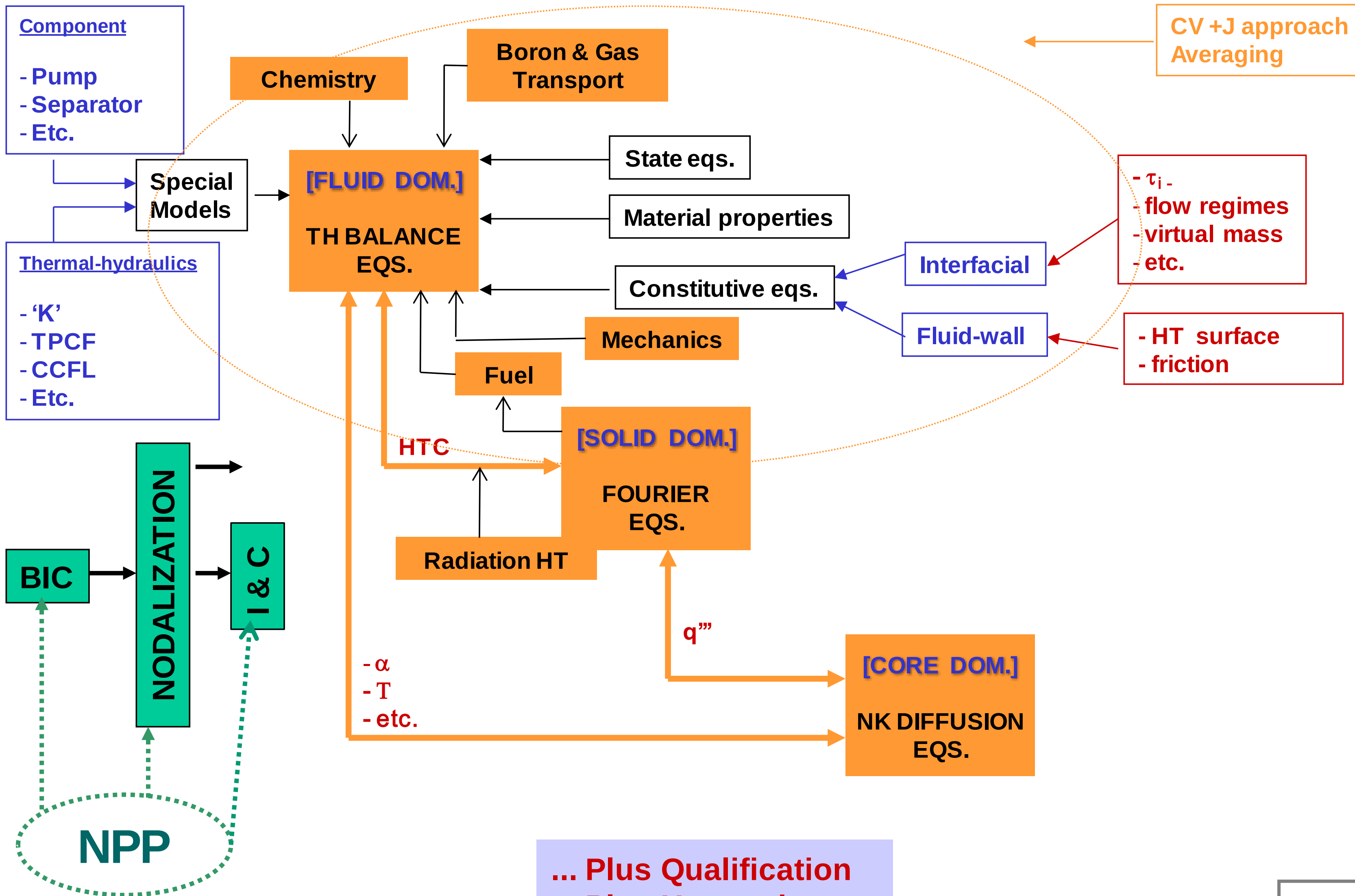
*(demonstration of)*
***ASSESSMENT OF ASSESSMENT***

| No | Type | Concerned NPP | Concerned phenomenon or DBA | Notes |
|---|---|---|---|---|
| 1 | Basic | - | Bottle emptying | To test code features |
| 2 | | | U-tube manometer | To test code features and dependency of results upon boundary conditions |
| 3 | | | Pressure drops in two phase flow | |
| 4 | SET | | TPCF | Key phenomenon for DBA Analysis |
| 5 | | PWR | Transient CHF | |
| 6 | ITF | | SBLOCA | |
| 7 | | | | Counterpart Test, to address the scaling issue |
| 8 | NPP | | | To perform Kv-scaled calculation |



# OUTLINE OF CURRENT V&V

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




... 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

# THE MOTIVATION FOR V & V & C

**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)***

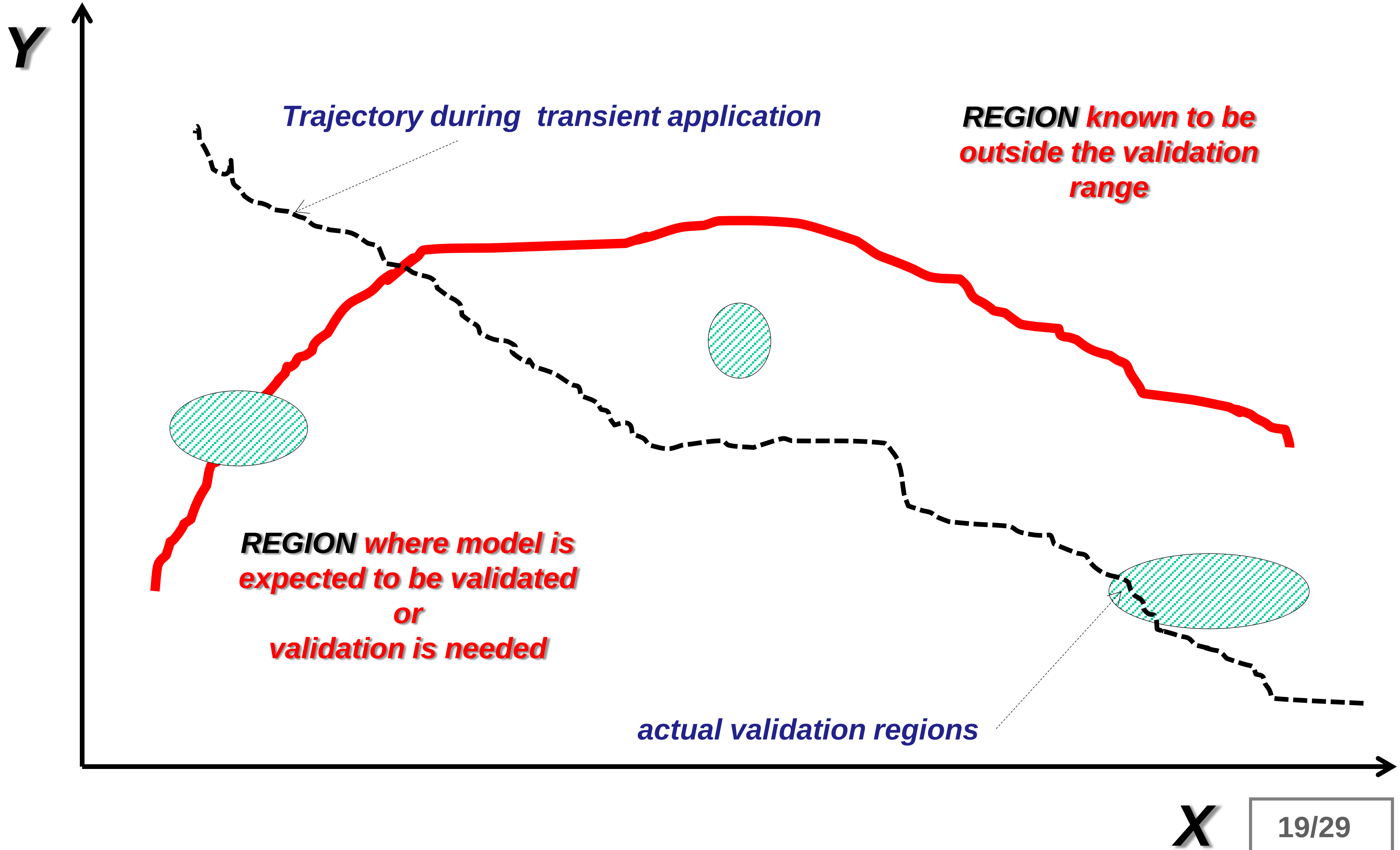
***PRIORITIZATION OF RESEARCH NEEDED***
***(to confirm adequacy of research strategy and needed V&V)***

***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



# THE MOTIVATION FOR V & V & C

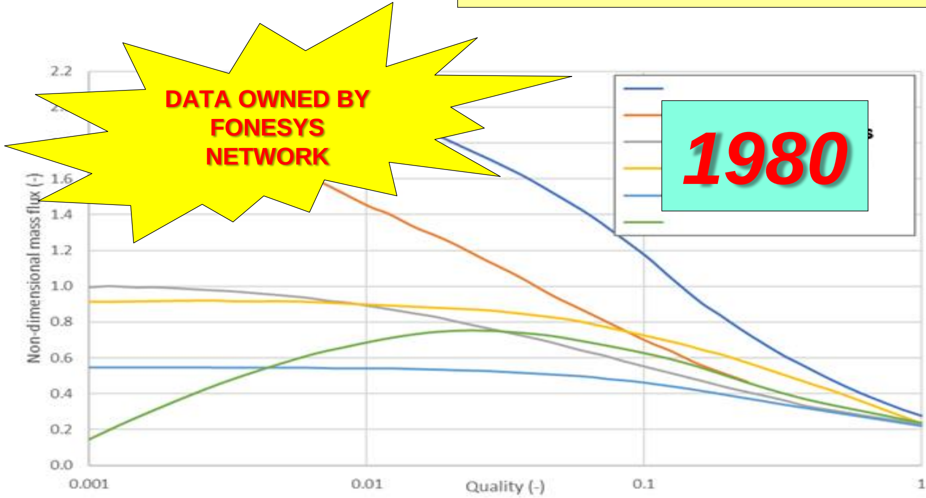
## 2) Inadequate experimental database (EXP-DB) - 2 of 2

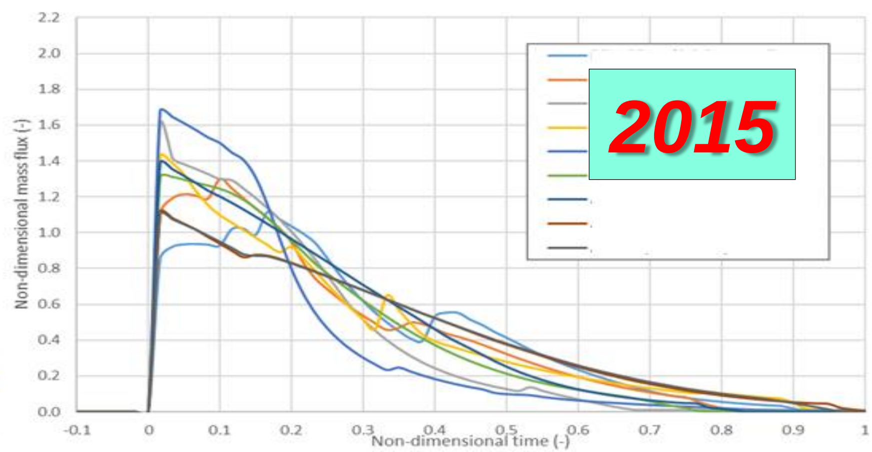
**CSNI SETF & ITF EXP-DB COVERS (<) < 1% parameter ranges / combinations expected in DBA of WCNR ➔ Situation may be worse looking at 116 TH phenomena.**

***EXP DB***
***ESSENTIAL FOR VALIDATION, BUT NOT ENOUGH***

***SURROGATE OF EXPERIMENTS NEEDED***

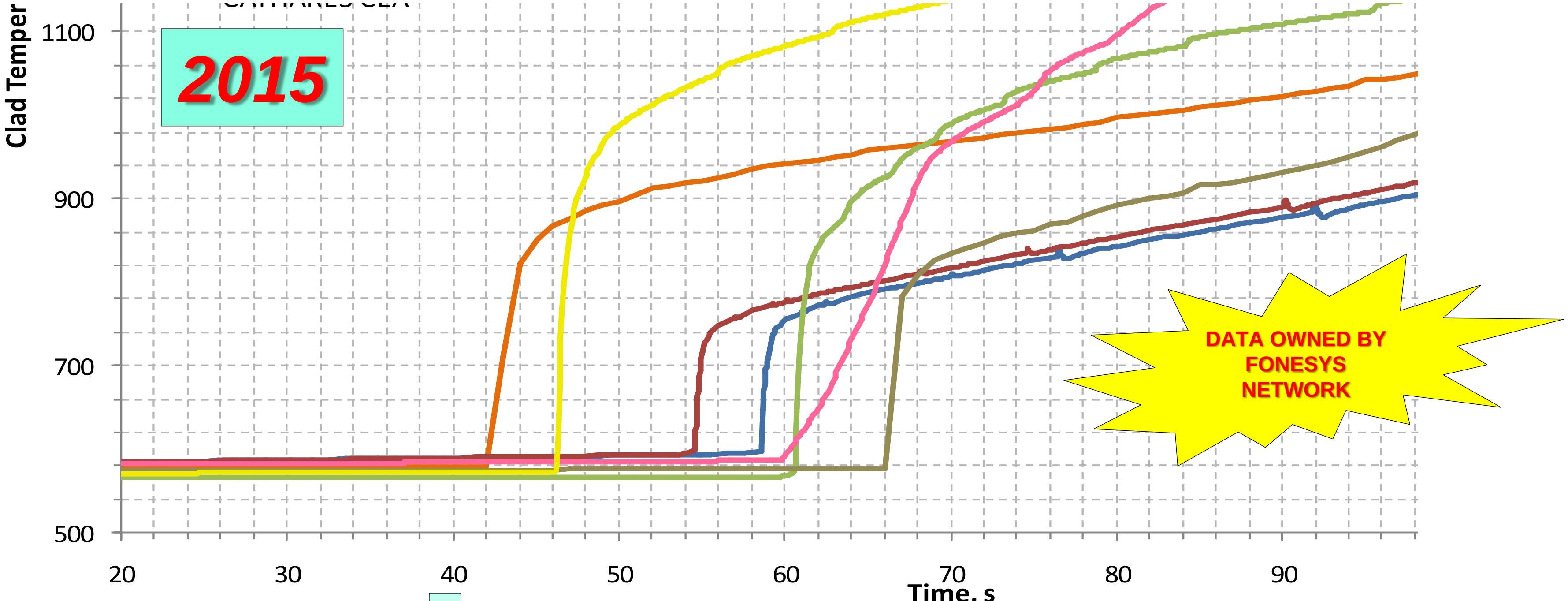
## 3) Inadequate V & V role: (a) - TPCF



# THE MOTIVATION FOR V & V & C

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




***CURRENT V & V***
***NOT ENOUGH TO IMPROVE MODELING CAPABILITIES***

***NEED TO ENLARGE THE SCOPE FOR V&V***

***➔ 'C'***

# THE DEFINITION OF 'C' = CONSISTENCY

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 <u>even in the absence of experimental evidence</u>, 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):

. :

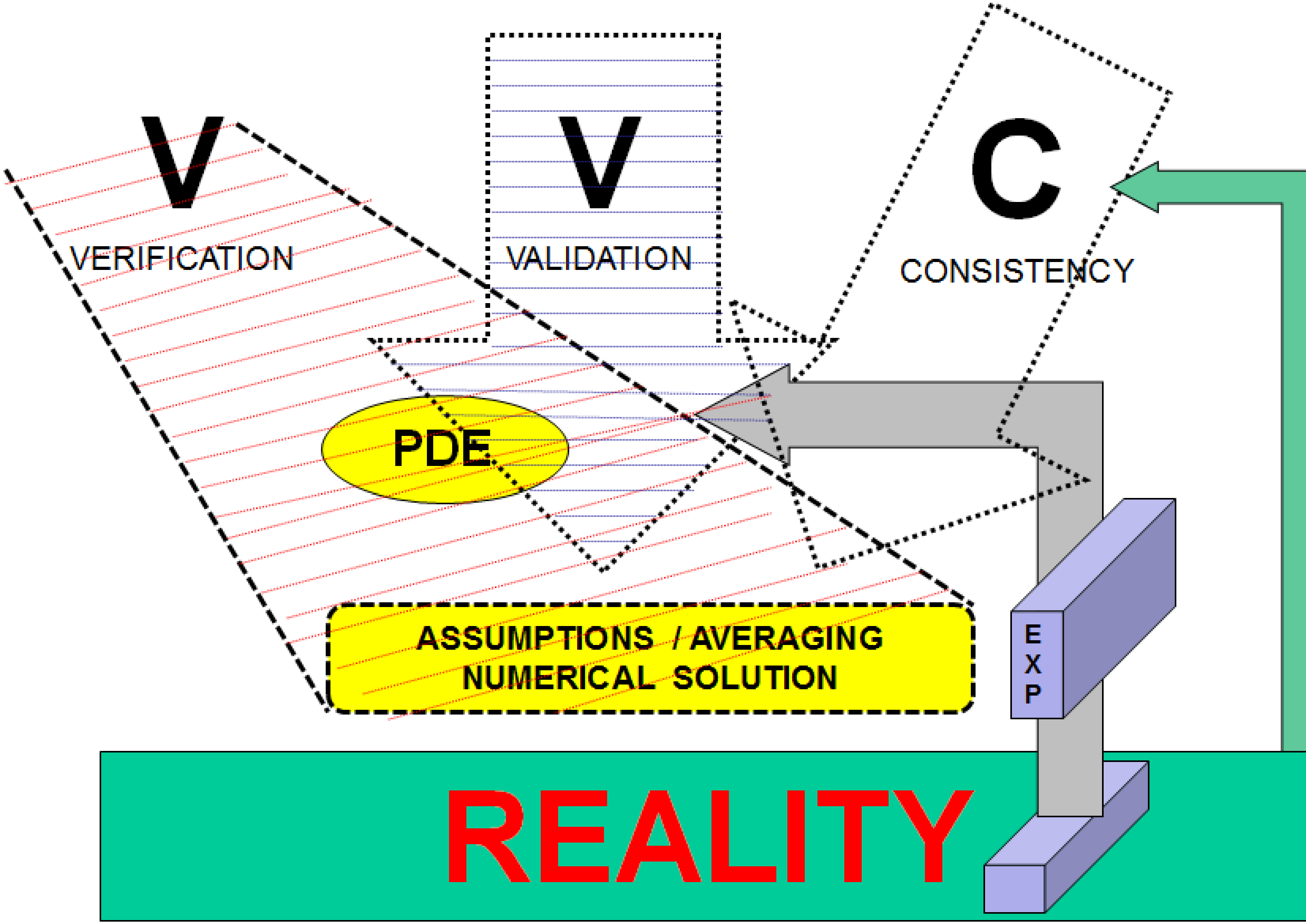
***'Consistency aims at filling gaps of V&V in nuclear thermal-hydraulics, with focus:***

***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***

***CROSSLINKING N-116-M-L***

***III) REQUIREMENTS***

***…. NEXT SLIDE ….***

# THE ROADMAP FOR V&V&C

## THE REQUIREMENTS FOR [V&V&]C

**<u>IIIa – General requirements (selected)</u>**

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. ϑ(output quantity) / ϑ(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 ROADMAP FOR V&V&C

## THE REQUIREMENTS FOR [V&V&]C

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

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

# 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 <u>CONSIDER BOTH</u>**
- **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