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IAEA TECDOC – Uncertainty Evaluation in Best Estimate Safety Analysis for Nuclear Power Plants

APPROACH AND METHODS TO EVALUATE THE UNCERTAINTY IN SYS-TH CALCULATIONS

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OECD/CSNI Workshop

Evaluation of Uncertainties in relation to Severe Accidents and Level 2 Probabilistic Safety Analysis

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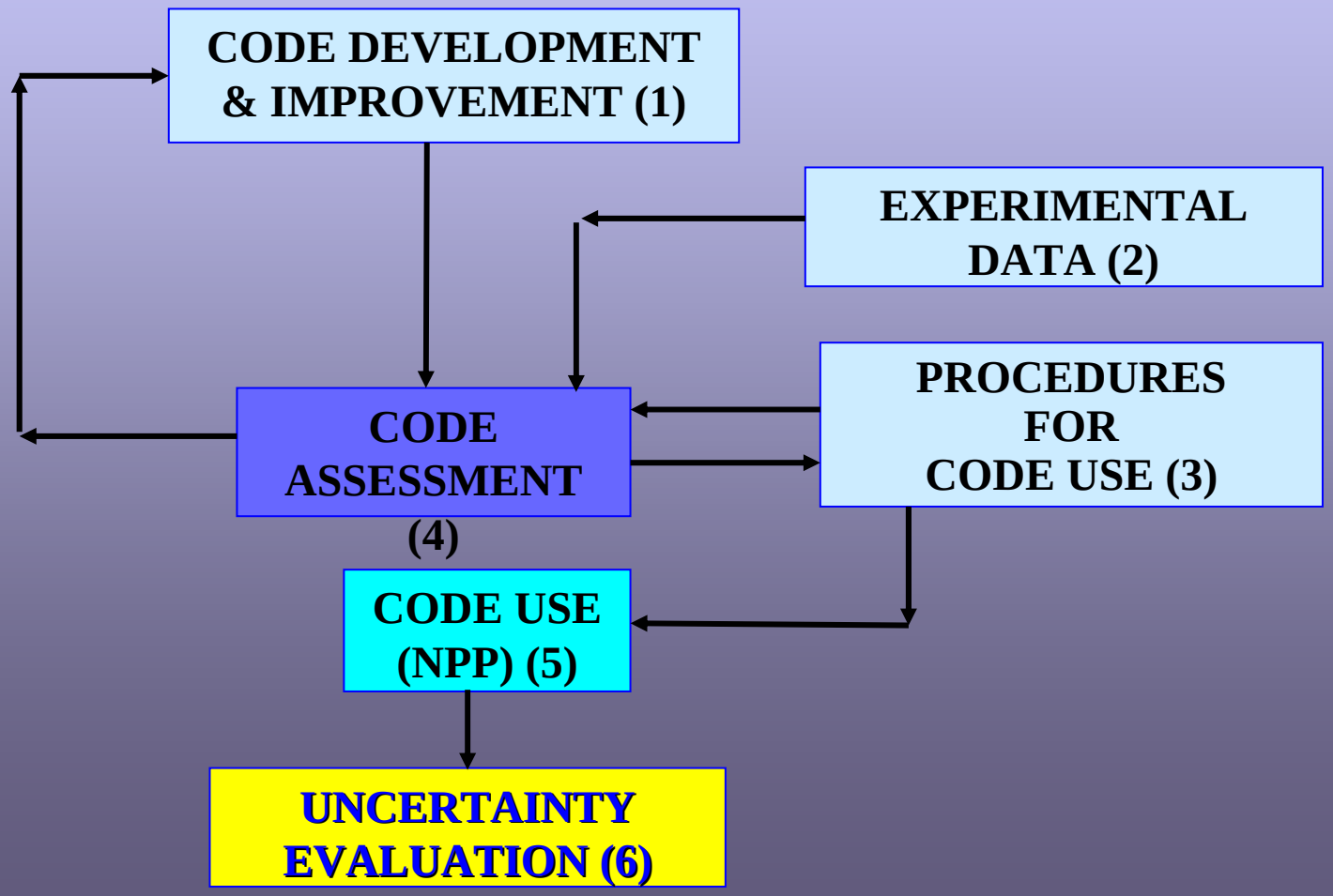
CONTENT

- ✓ Framework for Uncertainty in SYS-TH
- ✓ The Origin of Uncertainty
- ✓ The Approaches for Uncertainty
- ✓ Topics Relevant for Uncertainty Evaluation (TRUE)
- ✓ The CIAU Methodology
- ✓ Conclusions

Framework for Uncertainty in SYS-TH

NEEDS FOR UNCERTAINTY

CONSISTENT APPLICATION OF A THERMOHYDRAULIC SYSTEM CODE



The Origin of Uncertainty

A) Balance (or conservation) equations are approximate:

- Not all the interactions between steam and liquid are included;
- Equations solved within cylindrical pipes (no geometric discontinuity): situation not common for NPP. Lacking info to be supplied by code user.

B) Presence of different fields of the same phase: e.g. liquid droplets and film. Only one velocity per phase is considered by codes.

C) Geometry averaging at a cross section scale: POROUS MEDIA APPROACH. Velocity profiles happen in the reality: OPEN MEDIA APPROACH (CFD LIKE).

D) Geometry averaging at a volume scale: only one velocity vector (each phase) is associated with a hydraulic mesh along its axis.

Different velocity vectors may occur in the reality (inside LP, connection CL-DC)

E) Presence of large and small vortex or eddy. Energy and momentum dissipations not directly accounted.

A large vortex may determine system behaviour (e.g. two-phase natural circulation between hot and cold fuel bundles).

The Origin of Uncertainty

F) The 2nd principle of thermodynamics is not necessarily fulfilled by codes.

G) The numerical solution is approximate. Approximate equations are solved by approximate numerical methods.
The ‘amount’ of approximation is not documented.

H) Extensive use is made of empirical correlations:
- Range of validity not fully specified;
- Unavoidably used outside their range of validation;
- Approximately implemented into the code;
- Reference database affected by scatter and errors.

I) Paradox: ‘Steady State’ & ‘Fully Developed’ (SS & FD) flow approximation adopted. However all qualified correlations must be derived under SS & FD conditions. Almost in no region of the NPP those conditions apply.

The Origin of Uncertainty

J) State and material properties are approximate. Specifically true for derivatives of water properties.

K) Code User Effect (UE) exists. Two or more groups of users having available the same code and the same input information do not achieve the same results. UE due to:

- nodalization development;
- interpreting supplied information (usually incomplete);
- accepting a steady state performance of the nodalization;
- interpreting transient results, planning sensitivity studies, modifying (arbitrarily) the nodalization.

L) The computer/compiler installation affects the predictions of a code (computer/compiler effect). Very recent computers, compilers, and code releases did not improve the situation depicted a number of years ago.

The Origin of Uncertainty

M) Nodalization (N) effect exists. The N is the result of a wide range brainstorming process where user expertise, computer power and code manual play a role.

There is a number of required code input values that cannot be covered by logical recommendations: the user expertise needed to fix those may reveal inadequate.

N) Imperfect knowledge of Boundary and Initial Conditions (BIC). Some BIC values are unknown or known with approximation: the code user must add information.

O) Severe physical model deficiencies, which are unknown to the code user, cannot be excluded even in the latest versions of the advanced system codes.

The achieved results may flyaway from reality in a way not understandable by the code user.

The Approaches to Calculate Uncertainty

PRELIMINARY STATEMENTS FOR THE DESIGN OF AN UNCERTAINTY METHOD

- **Uncertainty Origins (UO) from A) to J) embedded into the Code.**
- **Effects of UO from K) to M) can be made milder by following Procedures, possibly part of Code Manuals.**
- **UO N) and O) have to be carefully considered.**
- **Definitely, all UO have to be considered when developing an Uncertainty Method.**

CURRENT SITUATION

- **A Dozen Methods Available. Reviews Published.**

The Approaches to Calculate Uncertainty

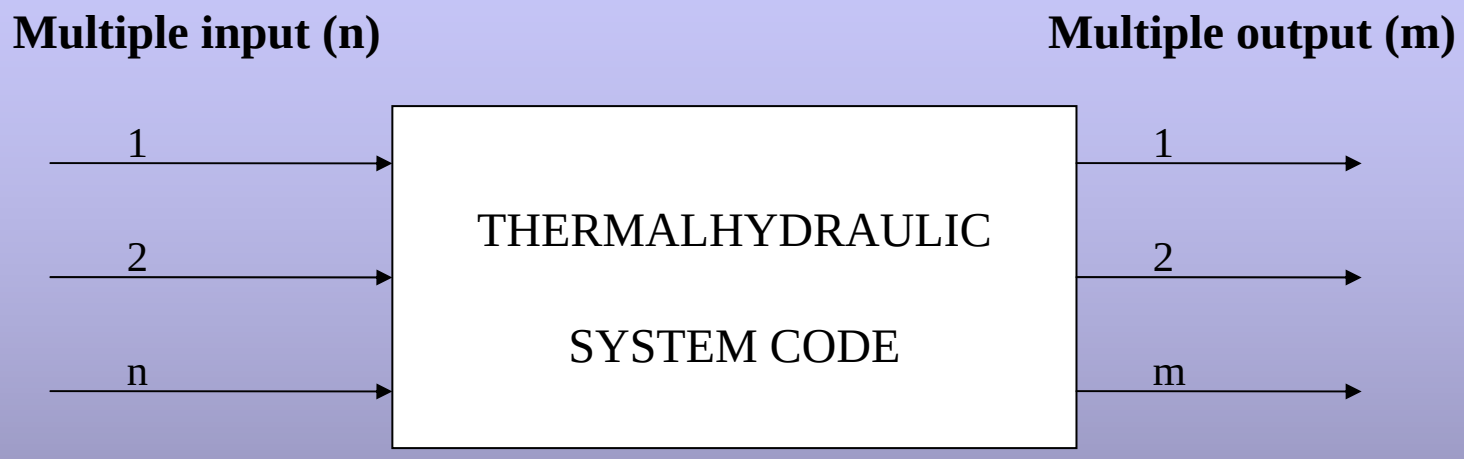
CLASSIFICATION ADOPTED HEREAFTER

- Difference between INPUT and OUTPUT PROPAGATION
  - PROPAGATION OF CODE INPUT "UNCERTAINTIES"
  - PROPAGATION OF CALCULATION OUTPUT "ERRORS"
- Alternative Classification
  - "PURELY" DETERMINISTIC METHOD
  - "PURELY" STATISTIC METHOD
  - USE OF STATISTICS

COMBINATIONS OF THE VARIOUS APPROACHES CAN BE PURSUED

The Approaches to Calculate Uncertainty

PROPAGATION OF CODE INPUT "UNCERTAINTIES"



- 'n' can be as large as 10^5
- the dimension of 'm' is not a main concern

THE PROPAGATION OF CODE INPUT UNCERTAINTIES IMPLIES THAT

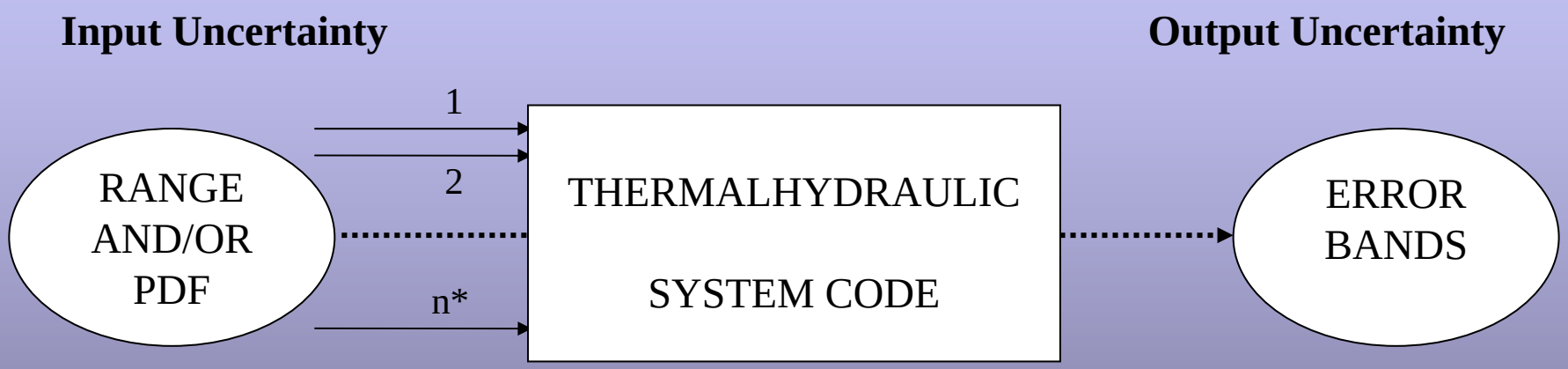
✓ 'n*' must be selected with 'n*' of the order of 10^2 and << 'n'

✓ range of variations and/or Probability Distribution Function (PDF) must be assigned to each of the 'n*' parameters

The Approaches to Calculate Uncertainty

PROPAGATION OF CODE INPUT "UNCERTAINTIES"

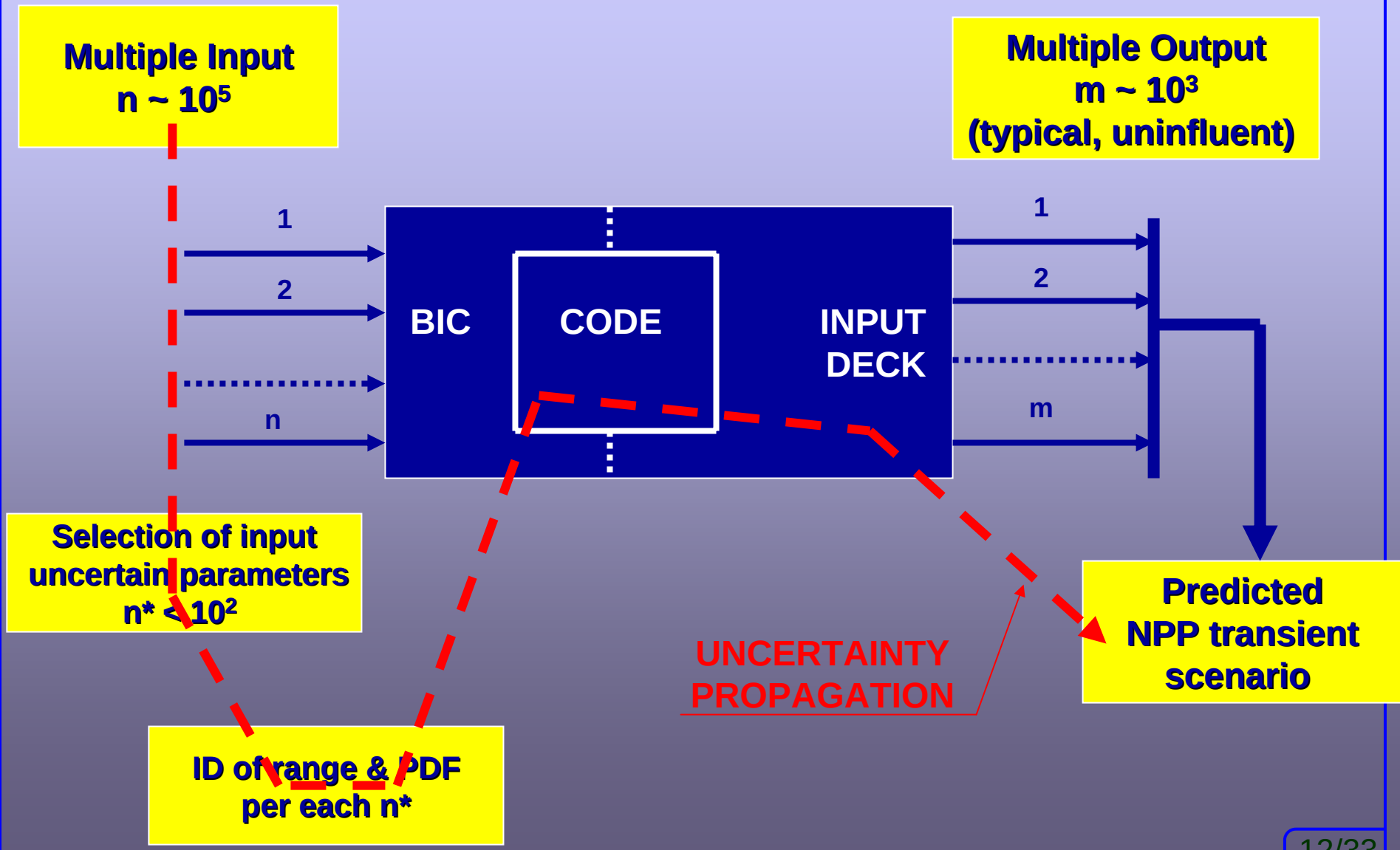
PATH FOR UNCERTAINTY EVALUATION



DRAWBACKS:

- Engineering judgment needed to select:
  - 'n*' starting from 'n'
  - range and/or PDF for each 'n*'
- The error propagation occurs through the code that, by definition, is an 'imperfect' tool

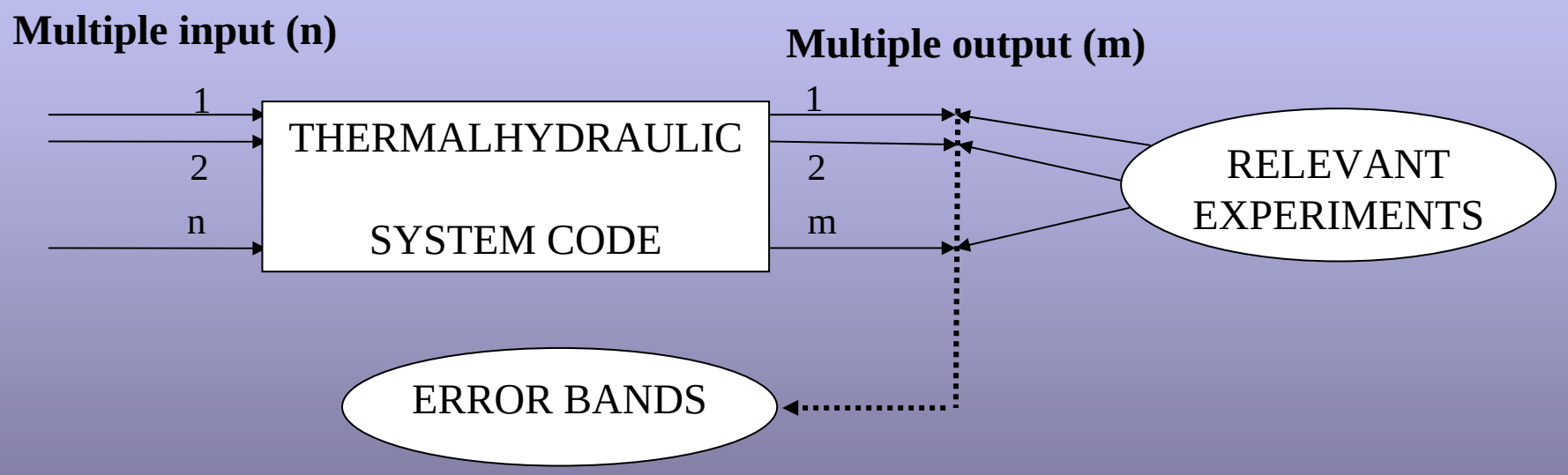
THE PROPAGATION OF INPUT UNCERTAINTIES



The Approaches to Calculate Uncertainty

PROPAGATION OF CALCULATION OUTPUT "ERRORS"

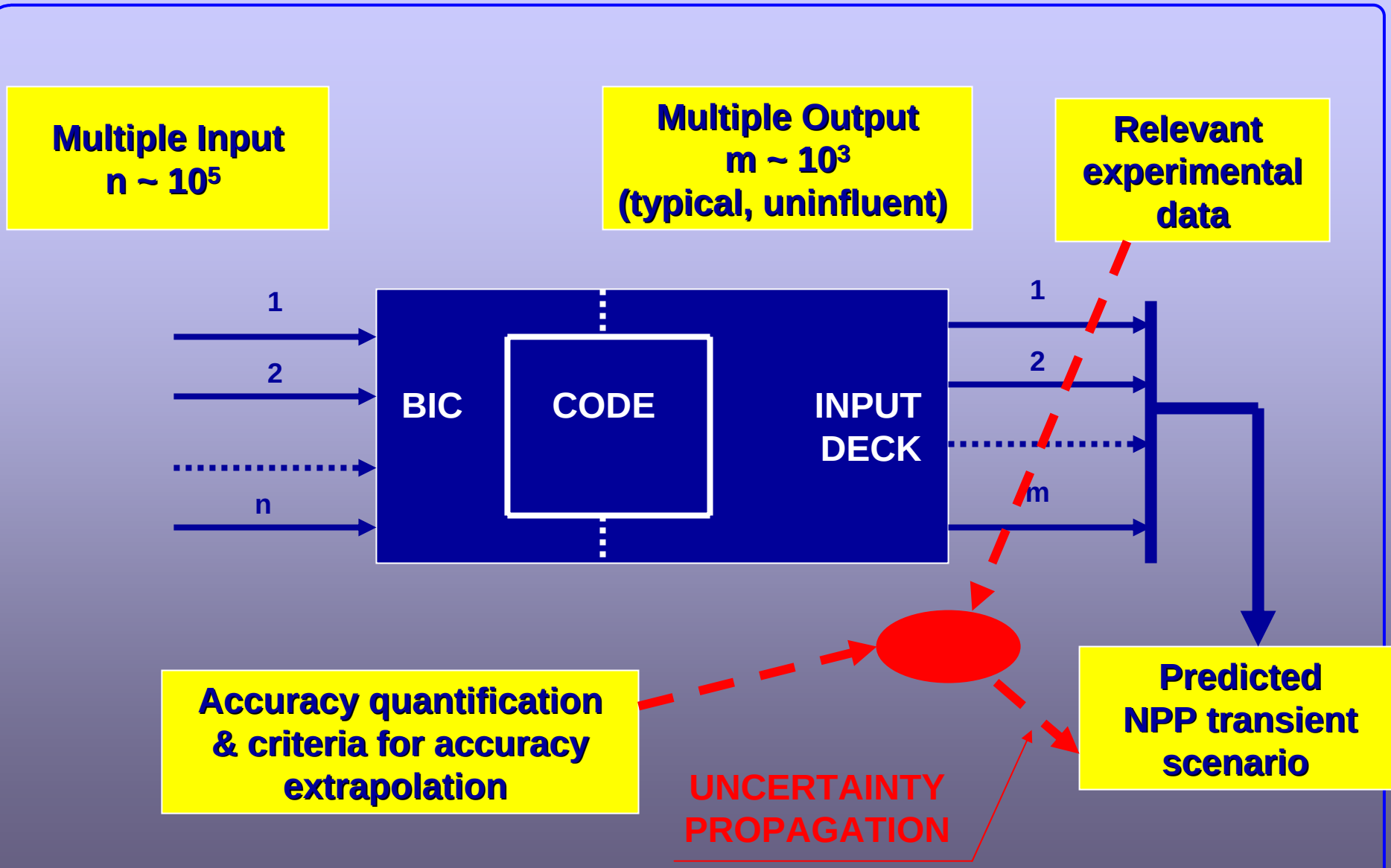
PATH FOR UNCERTAINTY EVALUATION



DRAWBACKS:

- The process of 'extrapolation' of output errors is not based upon fundamental principles
- It is impossible to distinguish contributions to the output error bands

THE PROPAGATION OF OUTPUT UNCERTAINTIES



Topics Relevant for Uncertainty Evaluation (TRUE)

1) NODALISATION CHOICES

Results from the LBLOCA DEGB DBA Angra-2 analysis: different input decks (nodalisation user choices) produce different effects upon relevant code output parameter, i.e. ΔPCT

2) CODE VERSIONS

Results from the SBLOCA BDBA UMS transient analysis: different code versions (same developer) have a strong impact in the prediction of a relevant uncertainty parameter, i.e. PCT

3) BIFURCATIONS

Results from a bifurcation study related to the SBLOCA BDBA UMS transient analysis. This study is possible with the availability of the Code with Capability of Internal Assessment of Uncertainty (CIAU).

NODALISATION CHOICES

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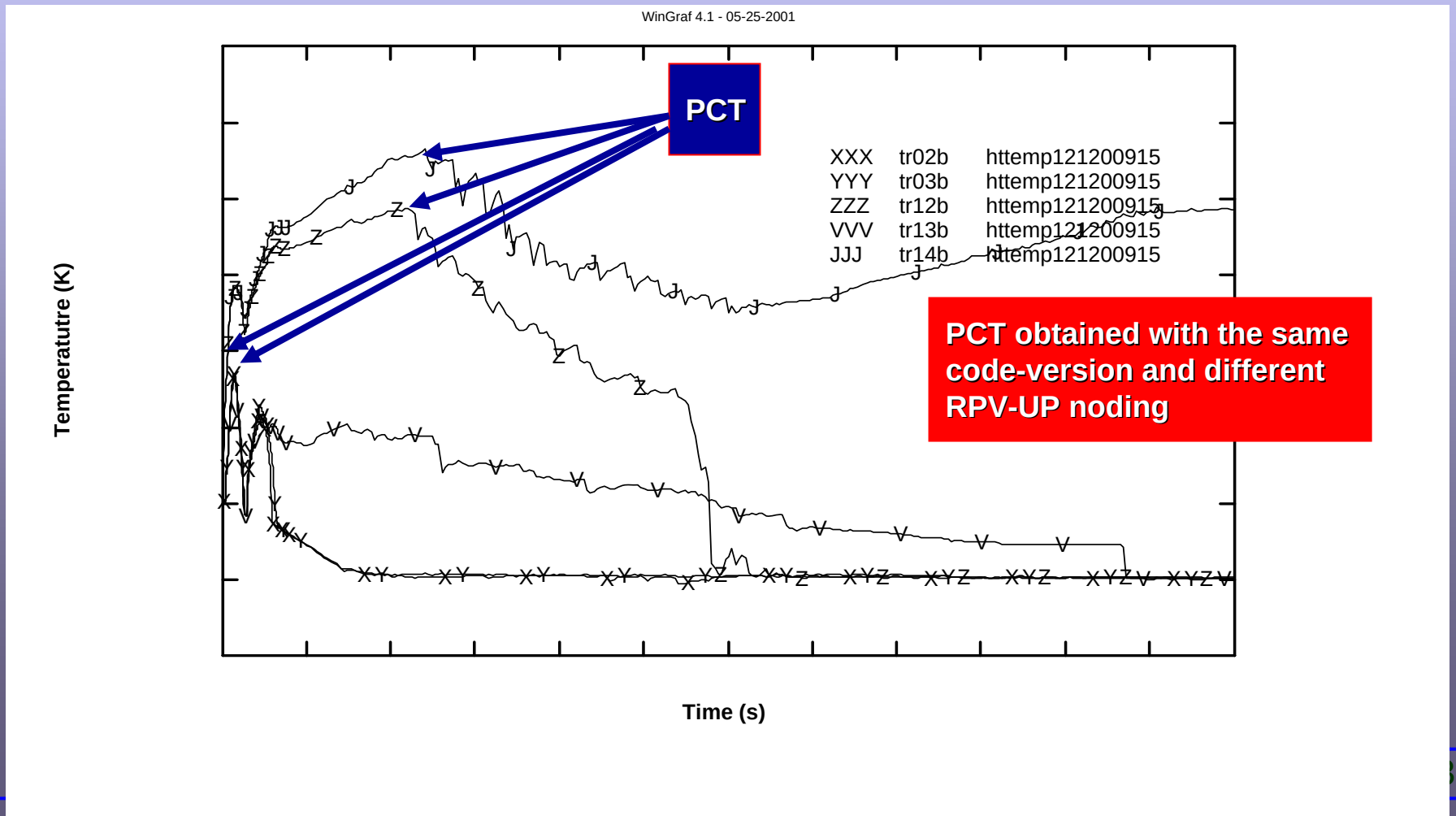
Internal Report, 2001



PCT obtained with the same code-version and different RPV-UP noding

NODALISATION CHOICES

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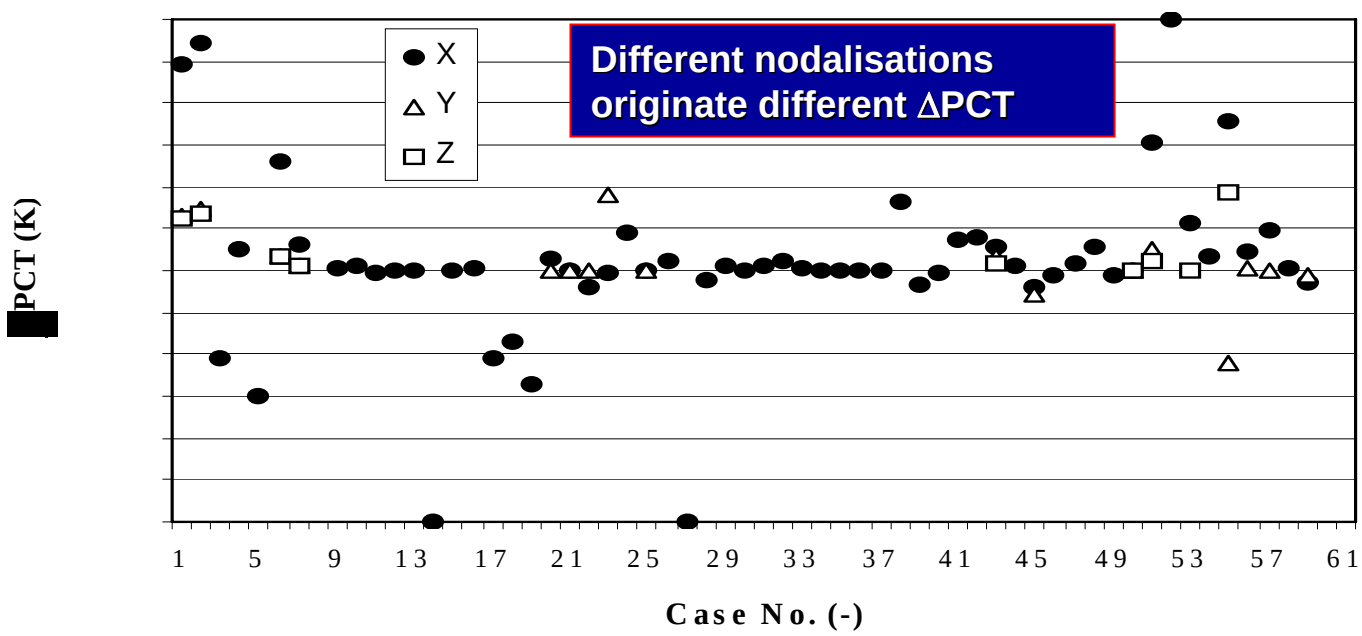
Internal Report, 2001

Two problems detected:

a) Reference PCT affected by nodalisation (choices)

b) ΔPCT strongly affected by nodalisation (i.e. a given input uncertain parameter is relevant or not depending upon the selected nodalisation (see the diagram below)

The conclusion at item b) is also applicable to different codes.



NODALISATION CHOICES

UNIPI
Internal Report, 2001

LESSON LEARNED

THE PROCESS OF PROPAGATING UNCERTAINTY THROUGH THE CODE (propagation of code input uncertainty) IS AFFECTED BY THE CODE AND BY THE NODALISATION:

AN ASSIGNED INPUT UNCERTAIN PARAMETER MAY AFFECT ΔPCT IN ONE DIRECTION OR IN ANOTHER DEPENDING UPON THE STRUCTURE OF THE INPUT DECK (AND OF THE CODE).

CODE VERSIONS/SAME INPUT DECK

Paper co-authored by UMS participants at BE-2000

After the closure of the Uncertainty Method Study (UMS) and after report /4/ was issued University of Pisa performed comparison calculations of experiment LSTF-SB-CL-18 using different versions of the RELAP 5 code, i.e. MOD 2, MOD 3.2 and MOD 3.2.2. Mod2 was used by the University of Pisa, and MOD 3.2 by AEA Technology as well as ENUSA in this study. It turned out that MOD 3.2 calculated a 170 K higher peak clad temperature compared with MOD 2 and MOD 3.2.2 (using the same input deck). This may contribute to the relative high upper limit of the uncertainty ranges calculated by AEAT and ENUSA. This is also in agreement with the AEAT peak clad temperature of 787 K at 300 s for their reference calculation using nominal values for the input parameters (without calculating the first heat-up). The measured peak is 610 K at 500 s.

CODE VERSIONS/SAME INPUT DECK

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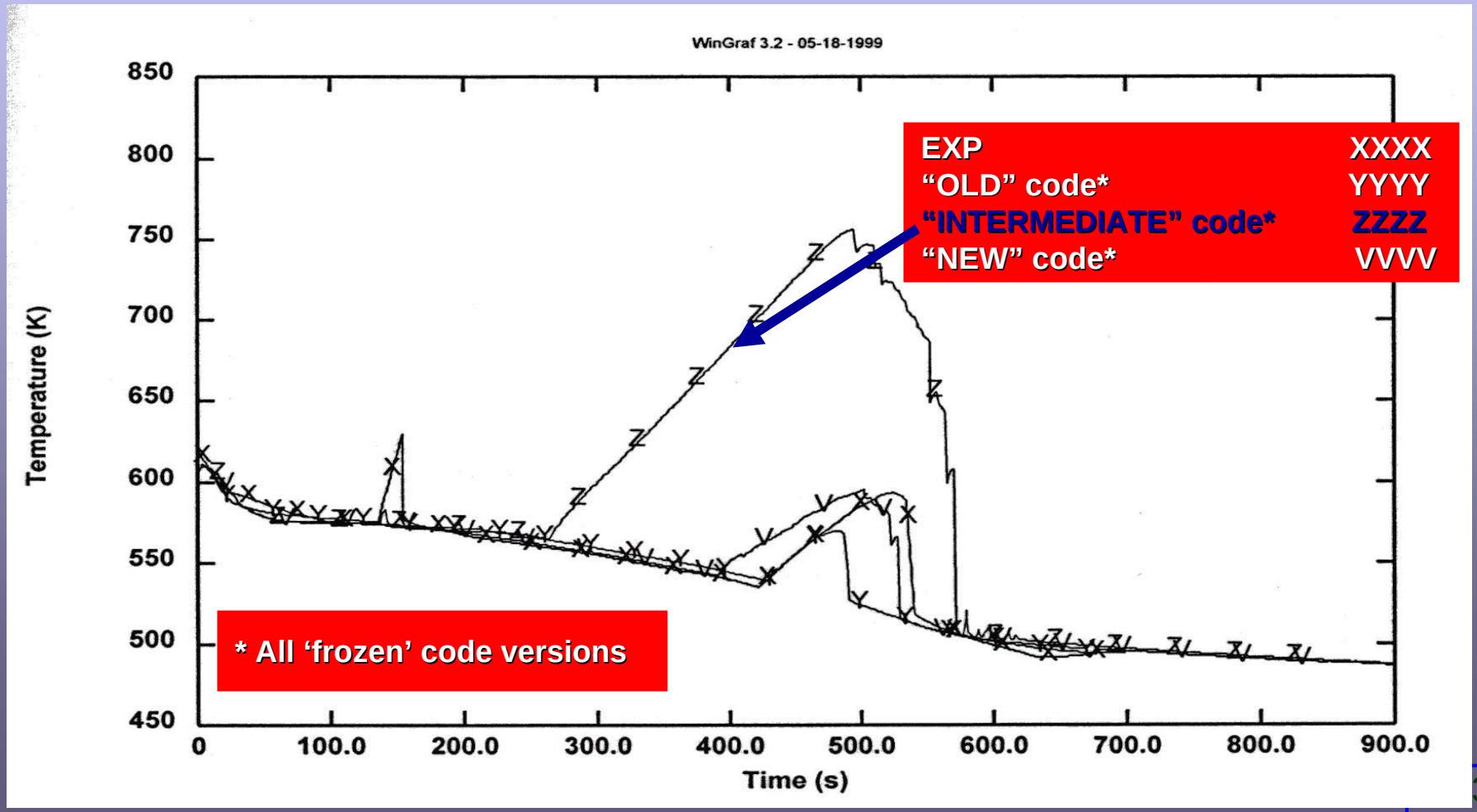

CODE VERSIONS/SAME INPUT DECK

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Internal Report, 1999

LESSON LEARNED

CODE VERSIONS (HIGHLY EVALUATEDAND QUALIFIED SYS-TH CODE), WITH THE SAME INPUT DECK, HAVE STRONG IMPACT UPON RESULTS AND AFFECT UNCERTAINTY PREDICTION

THEREFORE, 'DIRECT' SPECIFIC CODE QUALIFCIATION NEEDED FOR UNCERTAINTY EVALUATION

BIFURCATIONS

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Paper, 2000

SCENARIOS CAN BE IMAGINED WHERE BIFURCATIONS BRING THE TRANSIENT EVOLUTION FAR FROM THE BEST-ESTIMATE DETERMINISTIC PREDICTION, THUS INVALIDATING THE CONNECTED UNCERTAINTY EVALUATION.

THEREFORE, A BIFURCATION ANALYSIS MAY REVEAL NECESSARY.

STARTING POINTS FOR THE BIFURCATION ANALYSIS ARE:

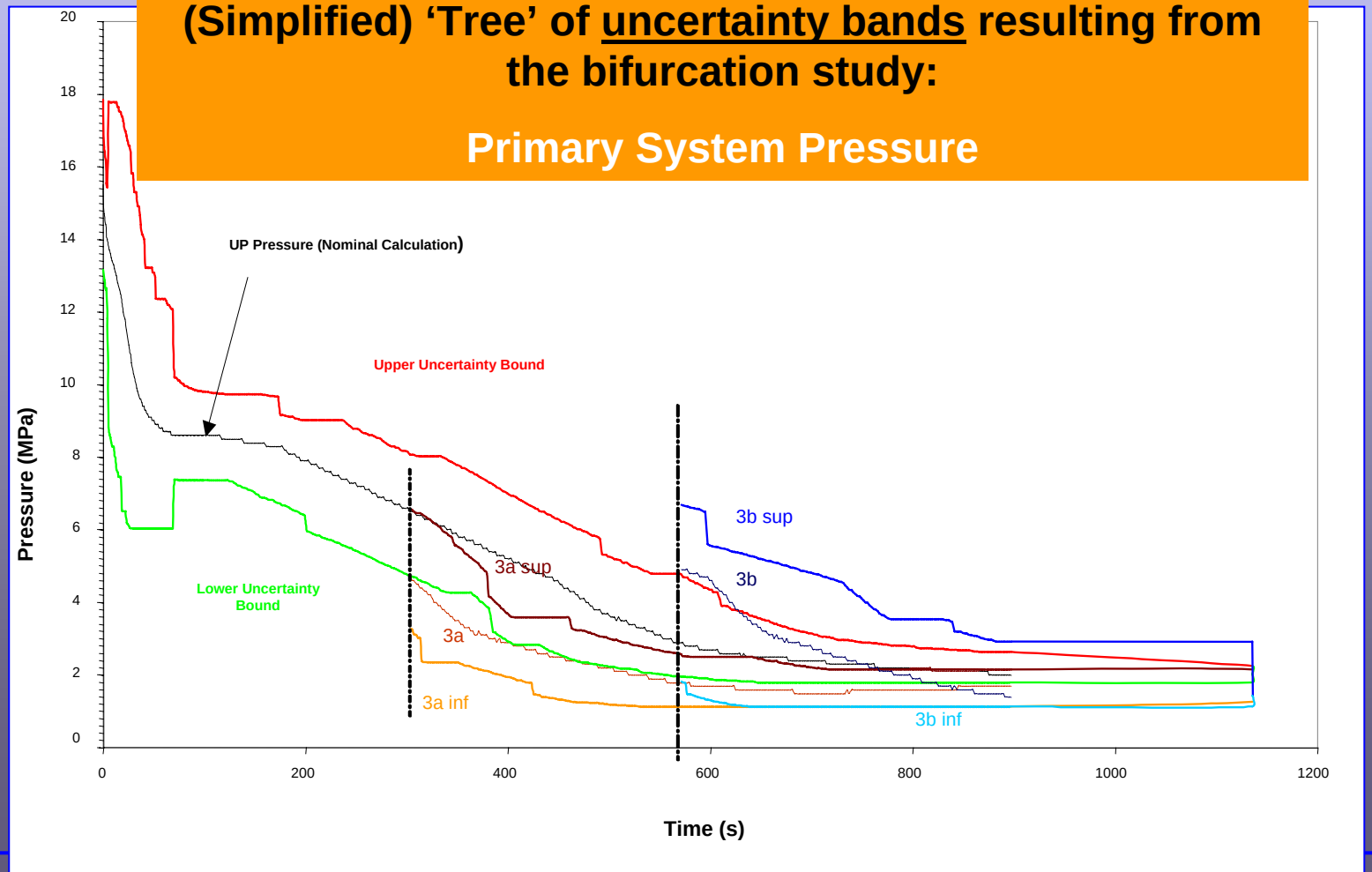
- THE IDENTIFICATION OF TYPE ONE AND OF TYPE TWO BIFURCATIONS
- THE KNOWLEDGE OF THE UNCERTAINTY CHARACTERIZING THE PARAMETERS WHICH AFFECT THE BIFURCATION.

BIFURCATIONS

UNIPI
Paper, 2000

(Simplified) 'Tree' of uncertainty bands resulting from the bifurcation study:

Primary System Pressure



BIFURCATIONS

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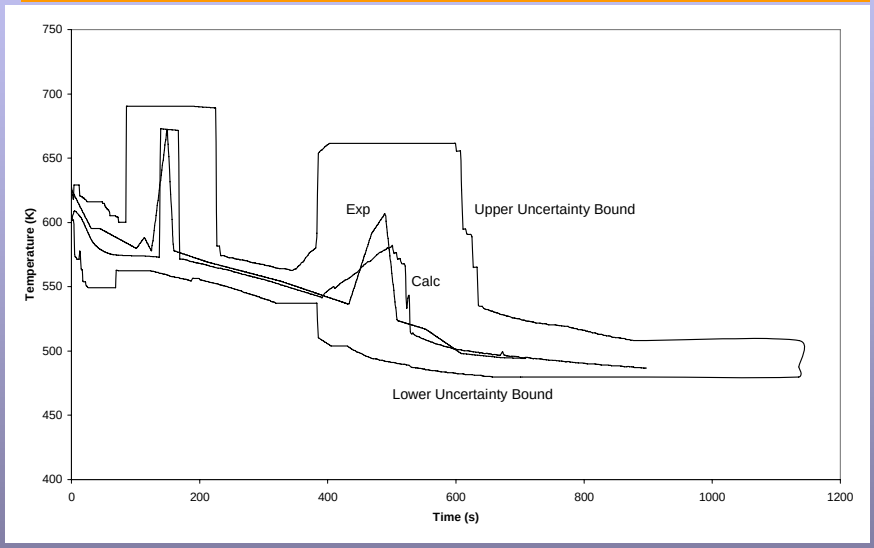
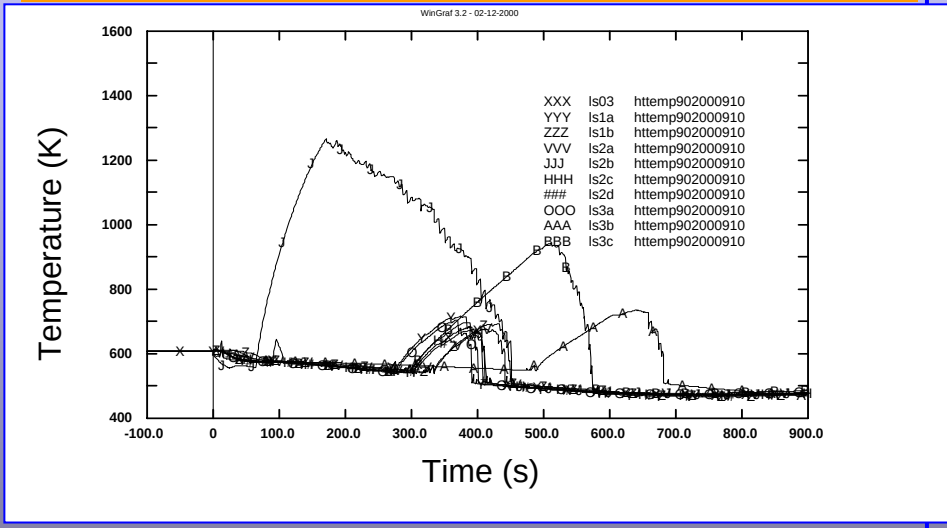
Paper, 2000

Standard CIAU application to UMS

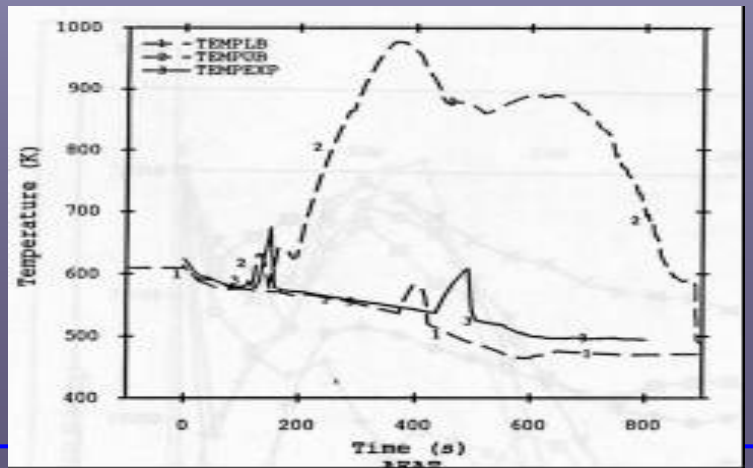


Bifurcation CIAU boundaries for UMS



UMS results obtained

By AEAT (and ENUSA)



BIFURCATIONS

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Paper, 2000

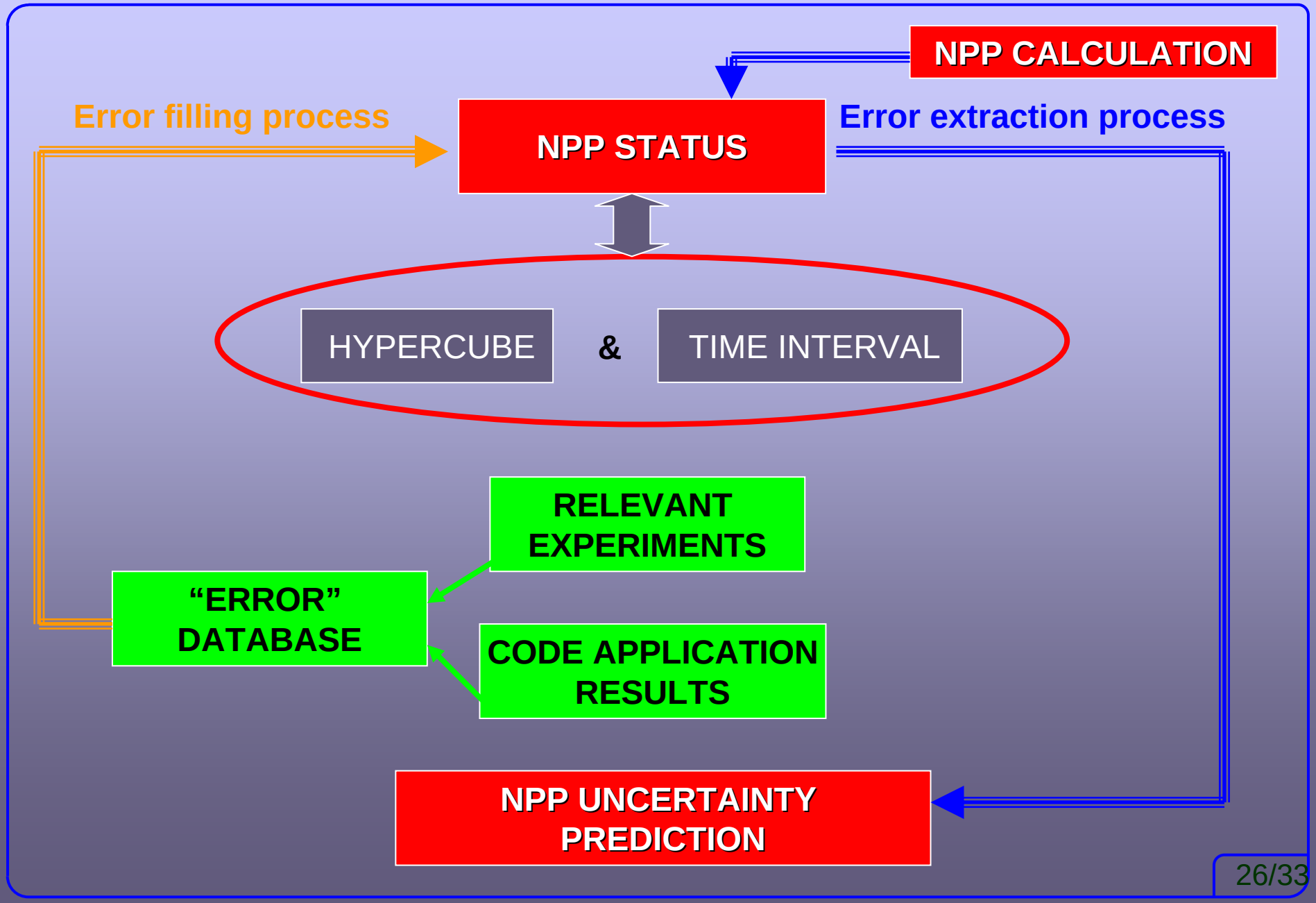
LESSON LEARNED

BIFURCATION STUDY IS POSSIBLE

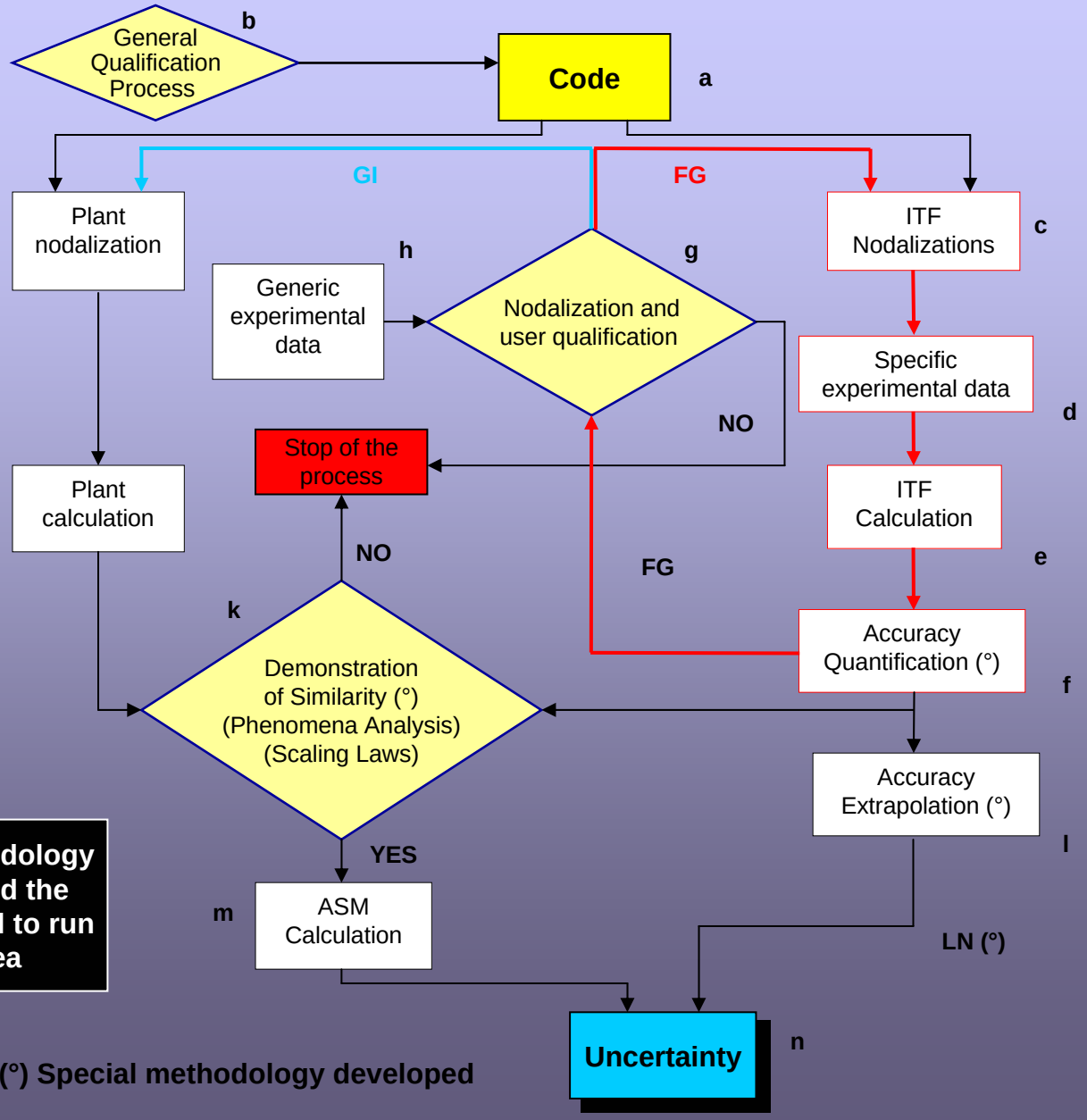
BIFURCATION STUDY PRODUCES (as expected) WIDER UNCERTAINTY BANDS (as related to the standard uncertainty study)

THE UMS AEAT (extreme) RESULT IS (basically) REPRODUCED BY THE CIAU BIFURCATION STUDY

The CIAU Method: the Idea



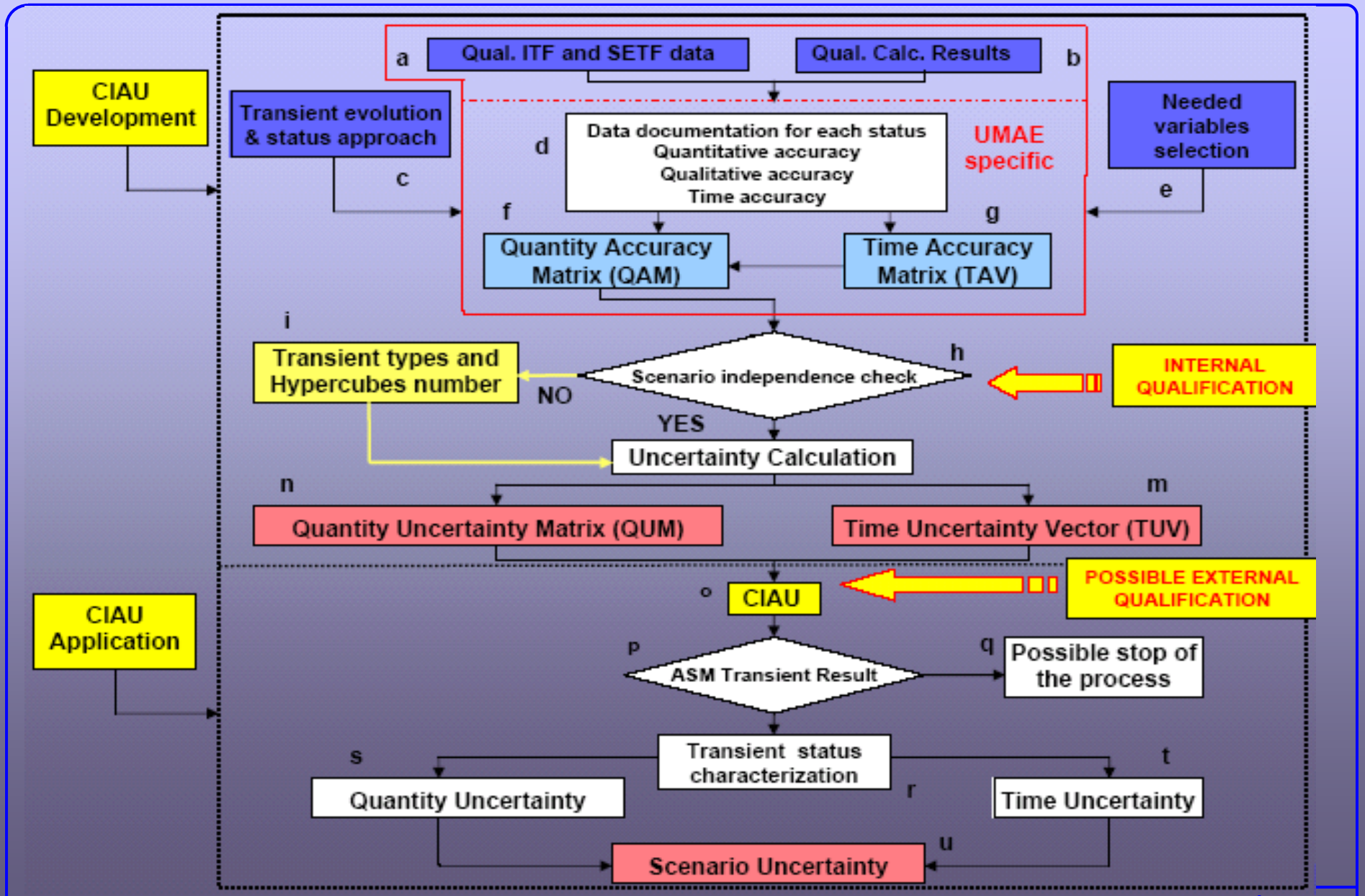
The CIAU Method: the Engine



The UMAE methodology is the Engine and the Qualification Tool to run the CIAU idea

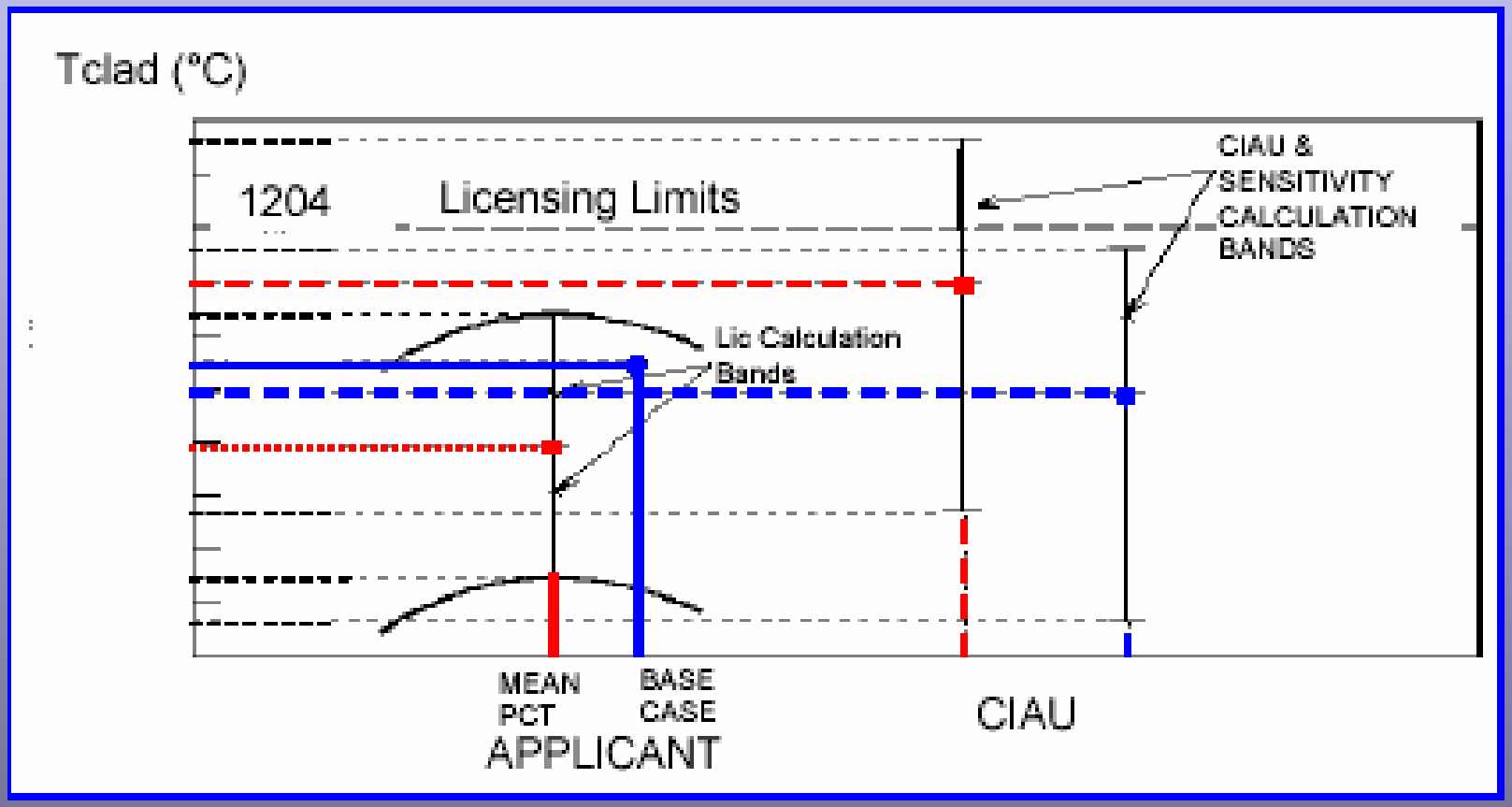
(°) Special methodology developed

The CIAU Method: the Flow-Diagram



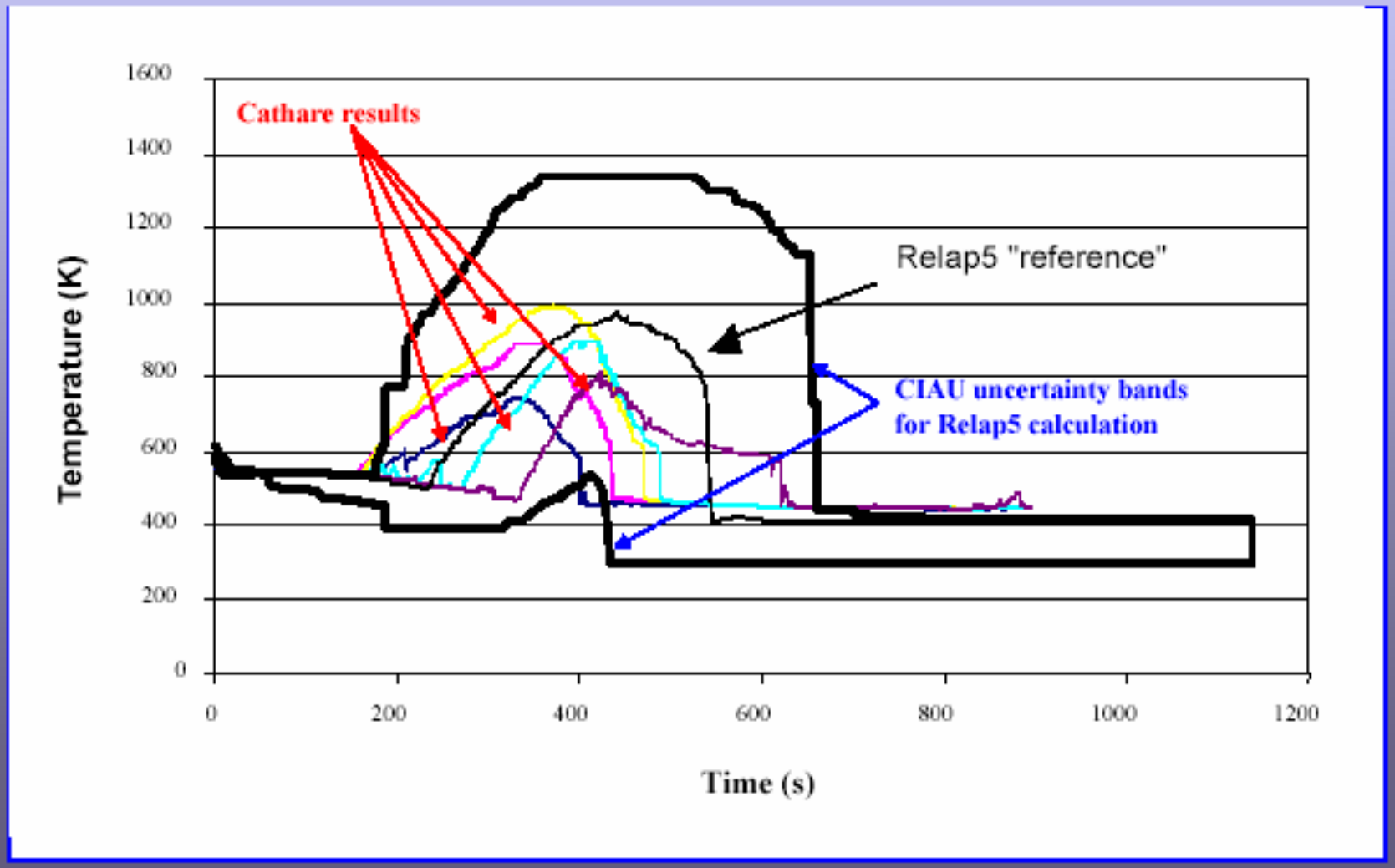
The CIAU Method: the Application

1) The Angra-2 DEGB licensing calculation



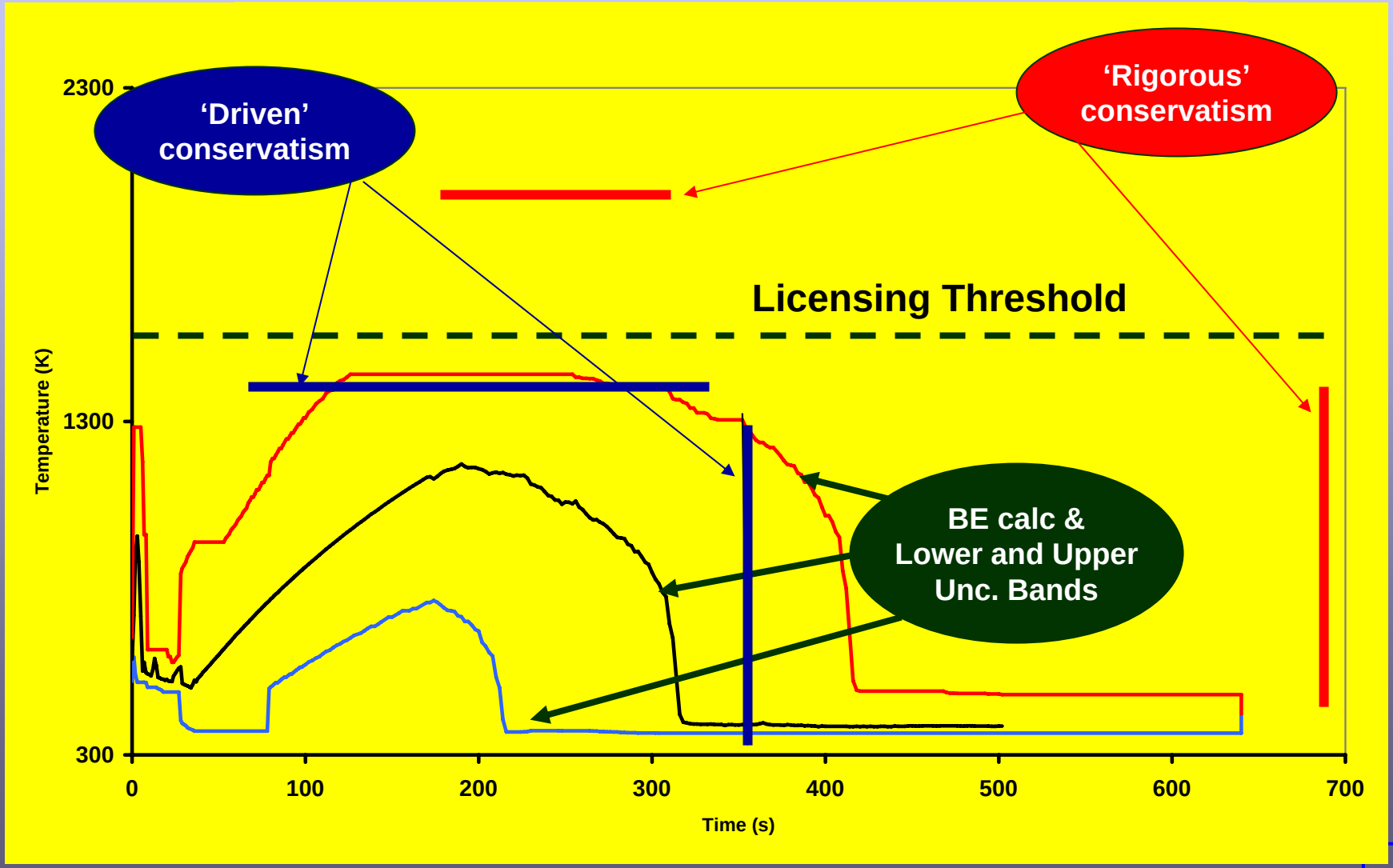
The CIAU Method: the Application

2) The Kozloduy-3 200 mm break to show similarity of code results



The CIAU Method: the Application

3) The Kozloduy-3 500 mm DEGB – support for demonstrating DBA



CONCLUSIONS

- ✓ **UNCERTAINTY ORIGINS IN TH-SYS CLASSIFIED.**
  - ***"USER EFFECT" AND "CV+J" APPROACH ARE IMPORTANT SOURCES OF UNCERTAINTY.***
- ✓ **APPROACHES FOR UNCERTAINTY IDENTIFIED.**
  - ***PROPAGATION OF <u>CODE INPUT UNCERTAINTY</u> & <u>PROPAGATION OF CODE OUTPUT ERROR</u> HAVE BEEN DISTINGUISHED***
- ✓ **TOPICS EMPHASIZED FOR UNCERTAINTY METHOD DEVELOPMENT & APPLICATION <u>(TRUE)</u> .**
- ✓ **MATURE UNCERTAINTY METHODS EXIST FOR DBA AND TH-SYS (ROLE OF 3D NK).**
  NEED TO SPREAD THE TECHNOLOGY
- ✓ **<u>CIAU</u> METHODOLOGY HAS BEEN OUTLINED.**
  - ***THE IDEA***
  - ***THE ENGINE***
  - ***THE RESULTS FROM APPLICATIONS***