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# UNCERTAINTY ANALYSIS METHODS FOR COUPLED NEUTRONICS-THE STATE OF THE ART, CRITICAL ISSUES AND NEEDS

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***Special Session on***
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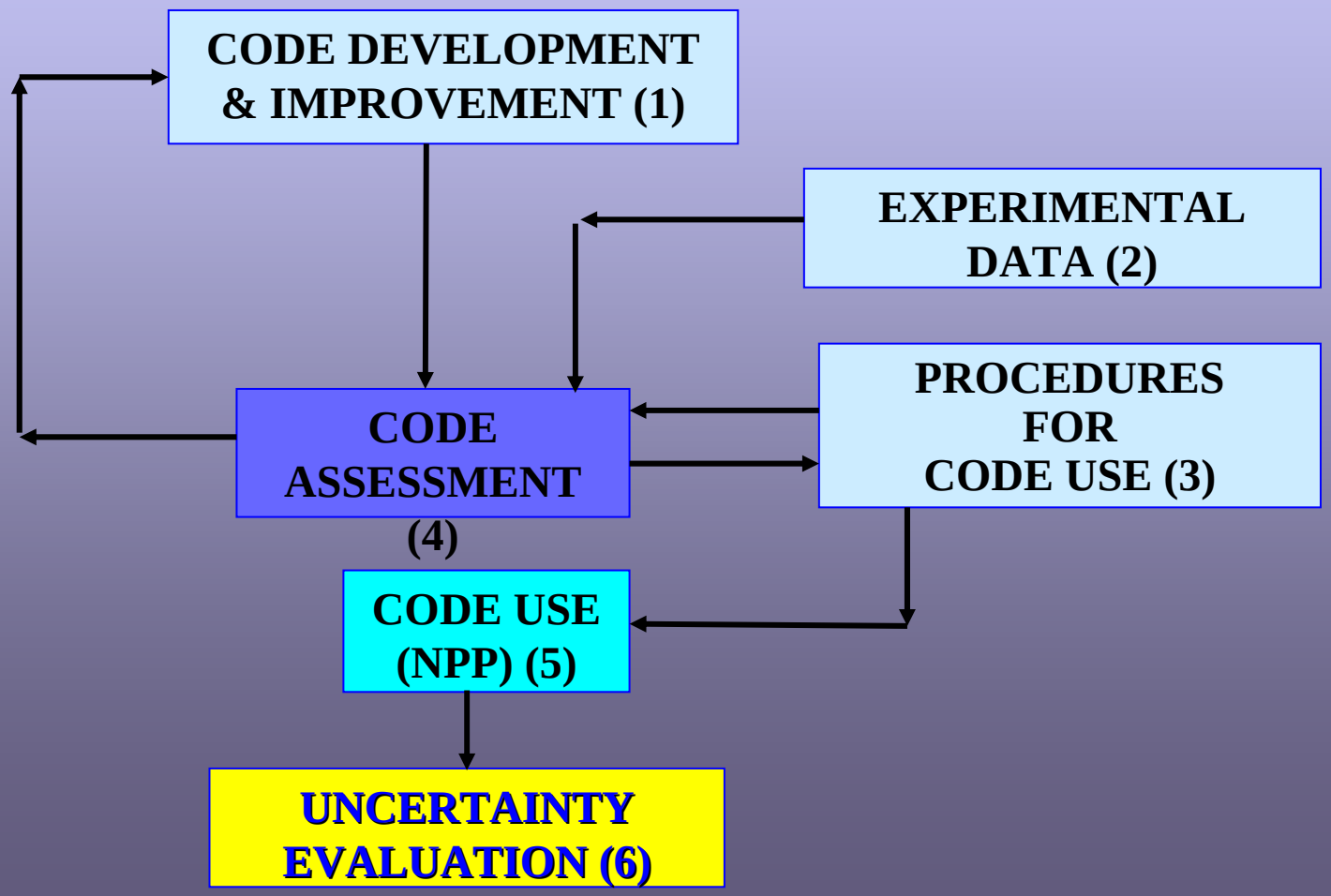
# CONTENT

- ✓ Framework for Uncertainty in SYS-TH
- ✓ The Origin of Uncertainty
- ✓ The Approaches for Uncertainty
- ✓ Topics Relevant for Uncertainty Evaluation (TRUE)
- ✓ The CIAU Methodology
- ✓ The Extension to 3D NK-TH Analysis
- ✓ 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

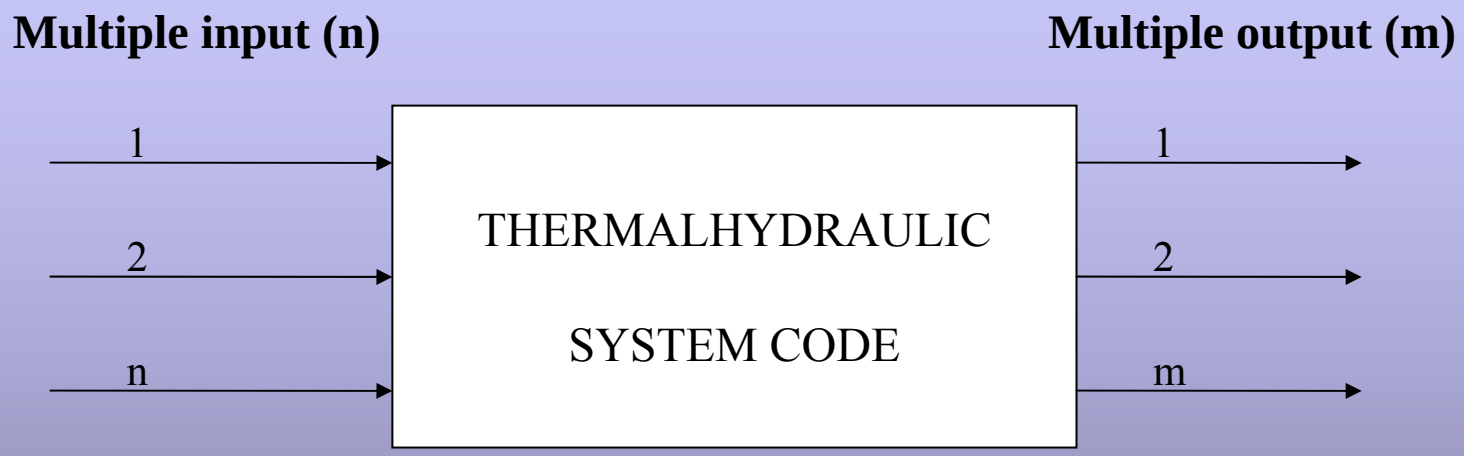
## CLASSIFICATION ADOPTED HEREAFTER

- 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**

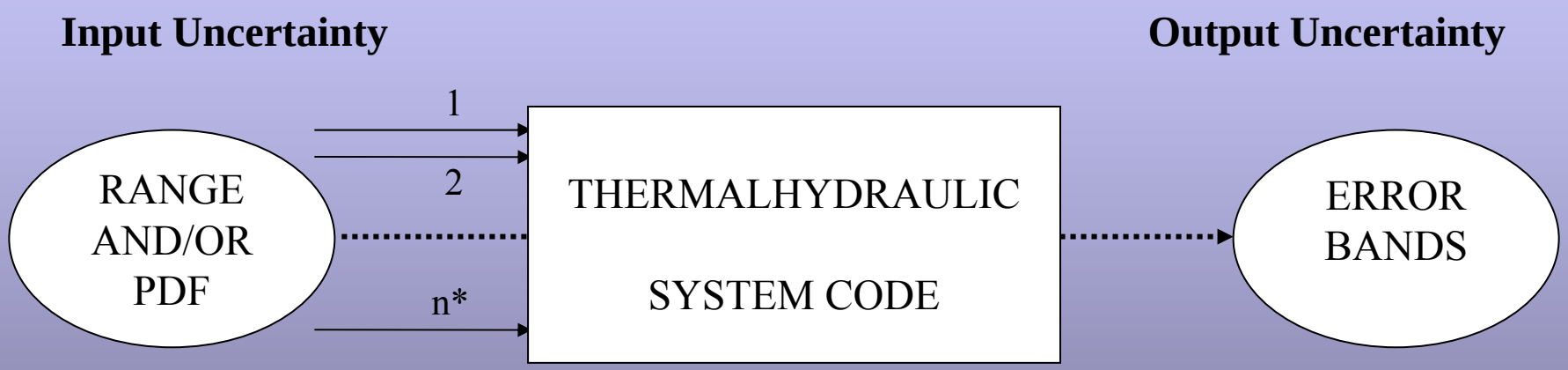
✓ 'n*' must be selected with 'n*' of the order of $10^2$ and << 'n'

✓ 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"

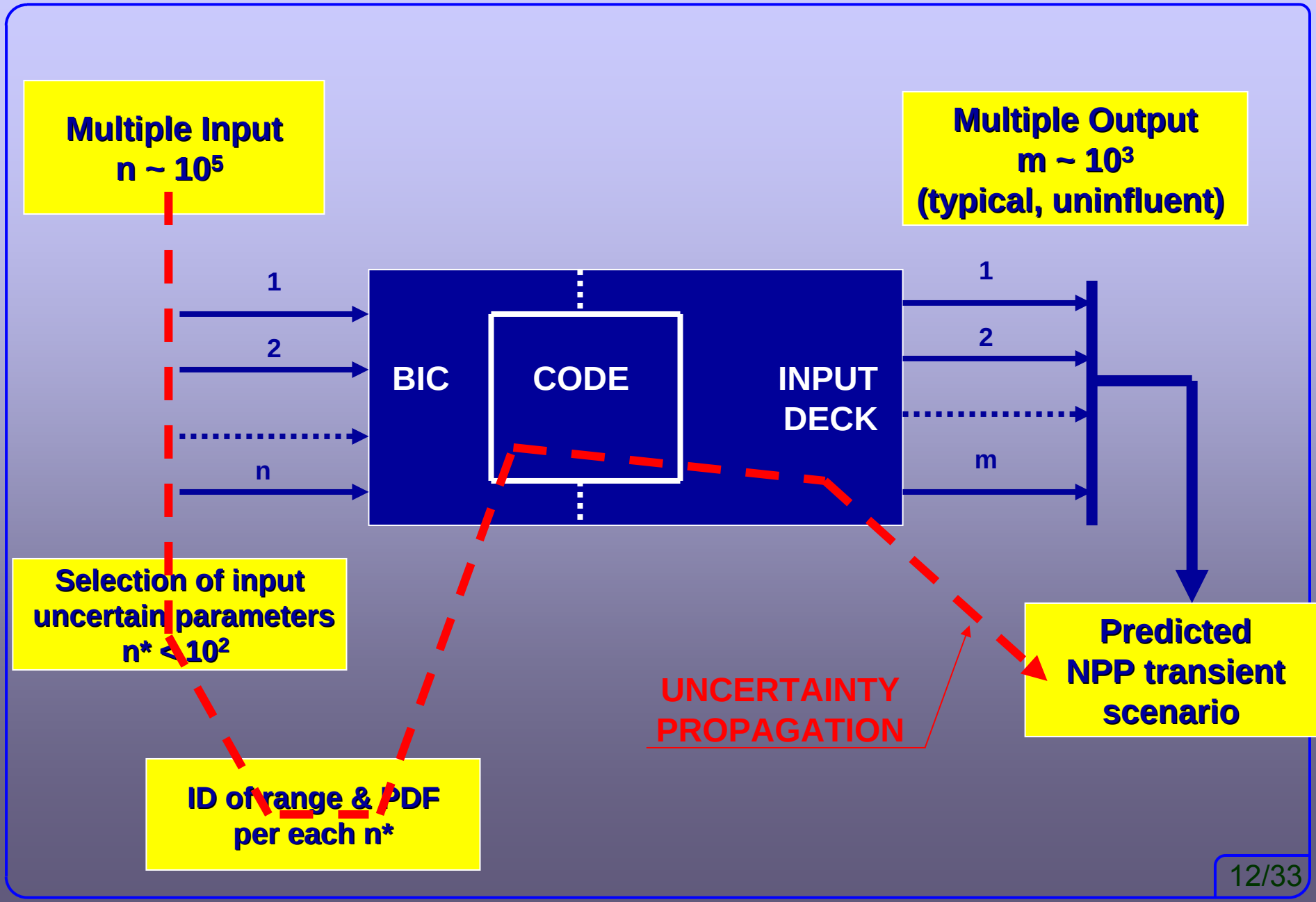
### PATH FOR UNCERTAINTY EVALUATION




## 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

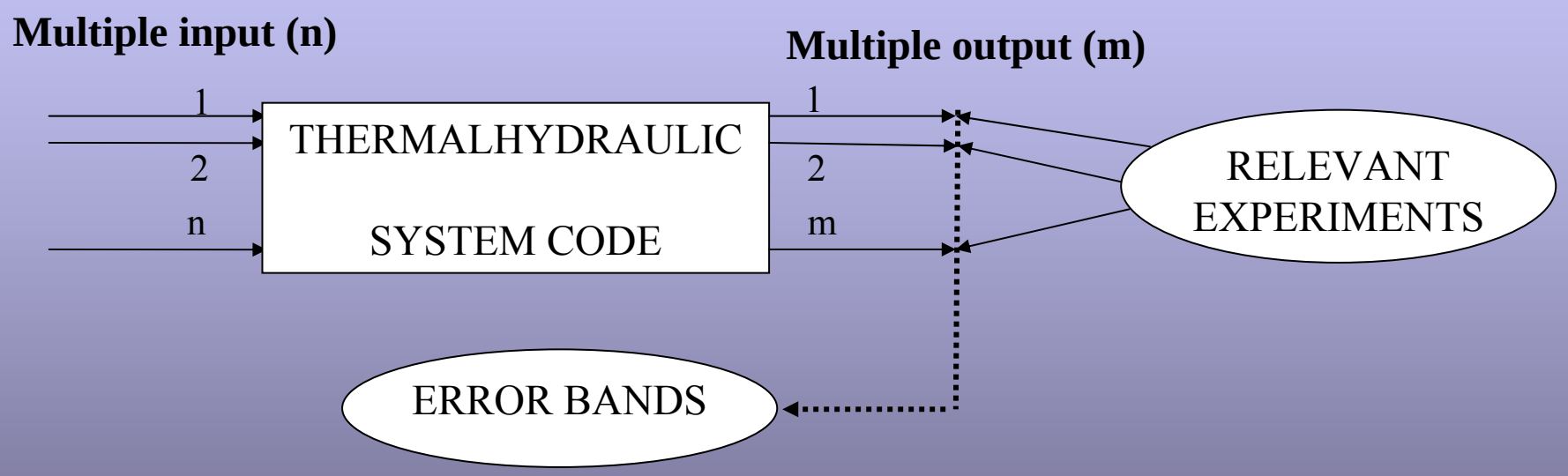
# THE PROPAGATION OF INPUT UNCERTAINTIES



# The Approaches to Calculate Uncertainty

## PROPAGATION OF CALCULATION OUTPUT "ERRORS"

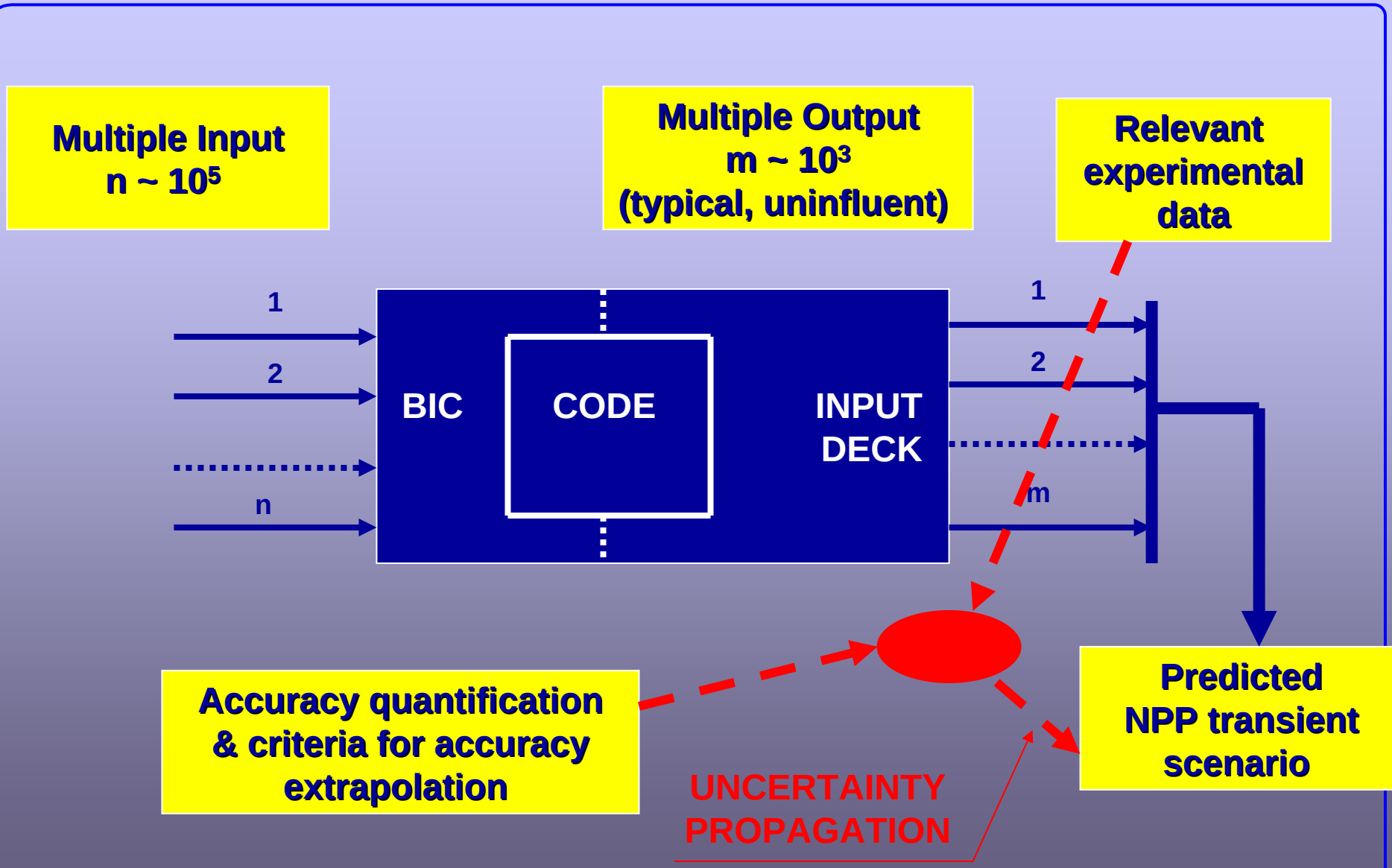
### PATH FOR UNCERTAINTY EVALUATION




## 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

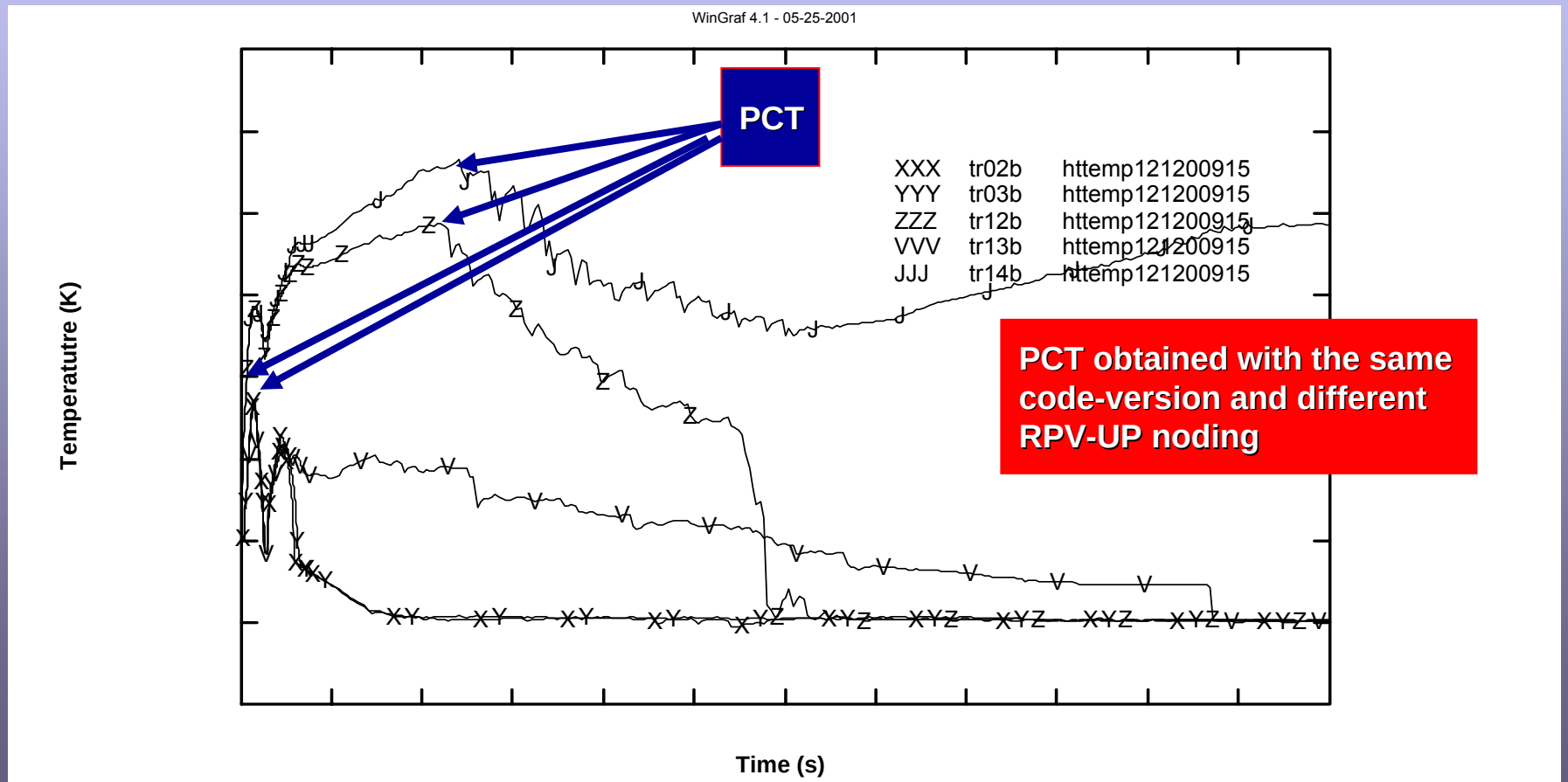
**Results from the SBLOCA BDBA UMS transient analysis: different code versions (same developer) have a strong impact in the prediction of a relevant uncertainty parameter, i.e. PCT**

## 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

**UNIPI**
**Internal Report, 2001**




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

# NODALISATION CHOICES

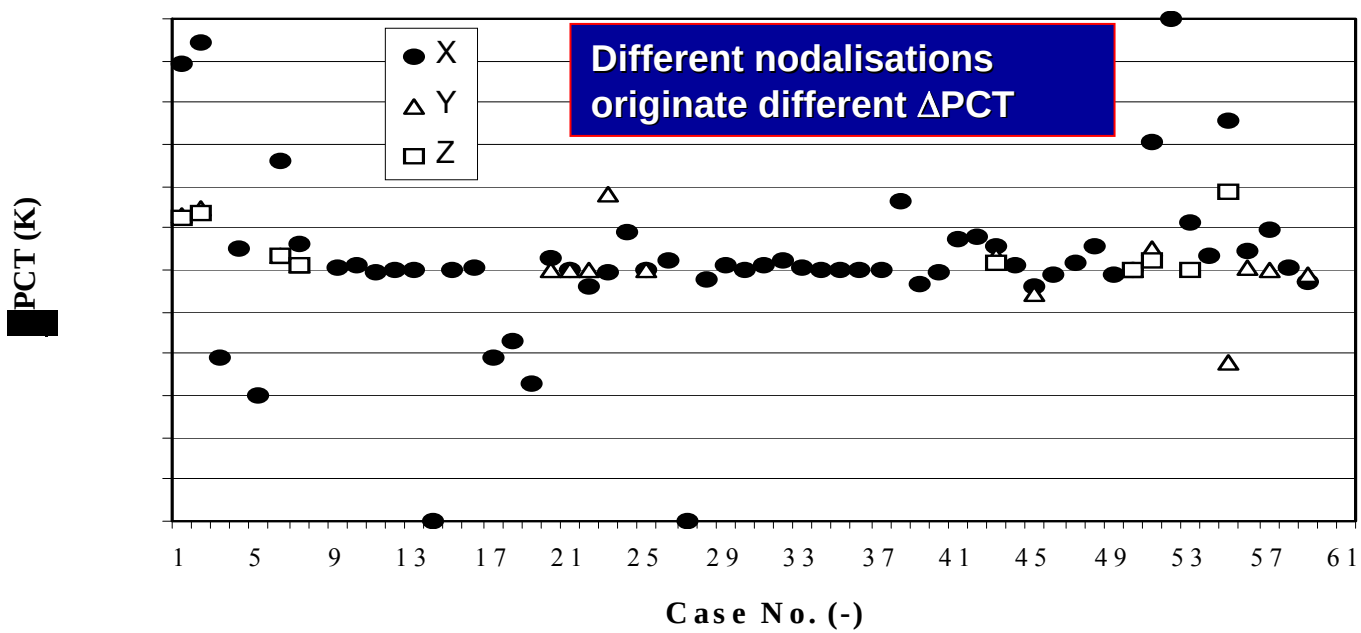
**UNIPI**
**Internal Report, 2001**

**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).

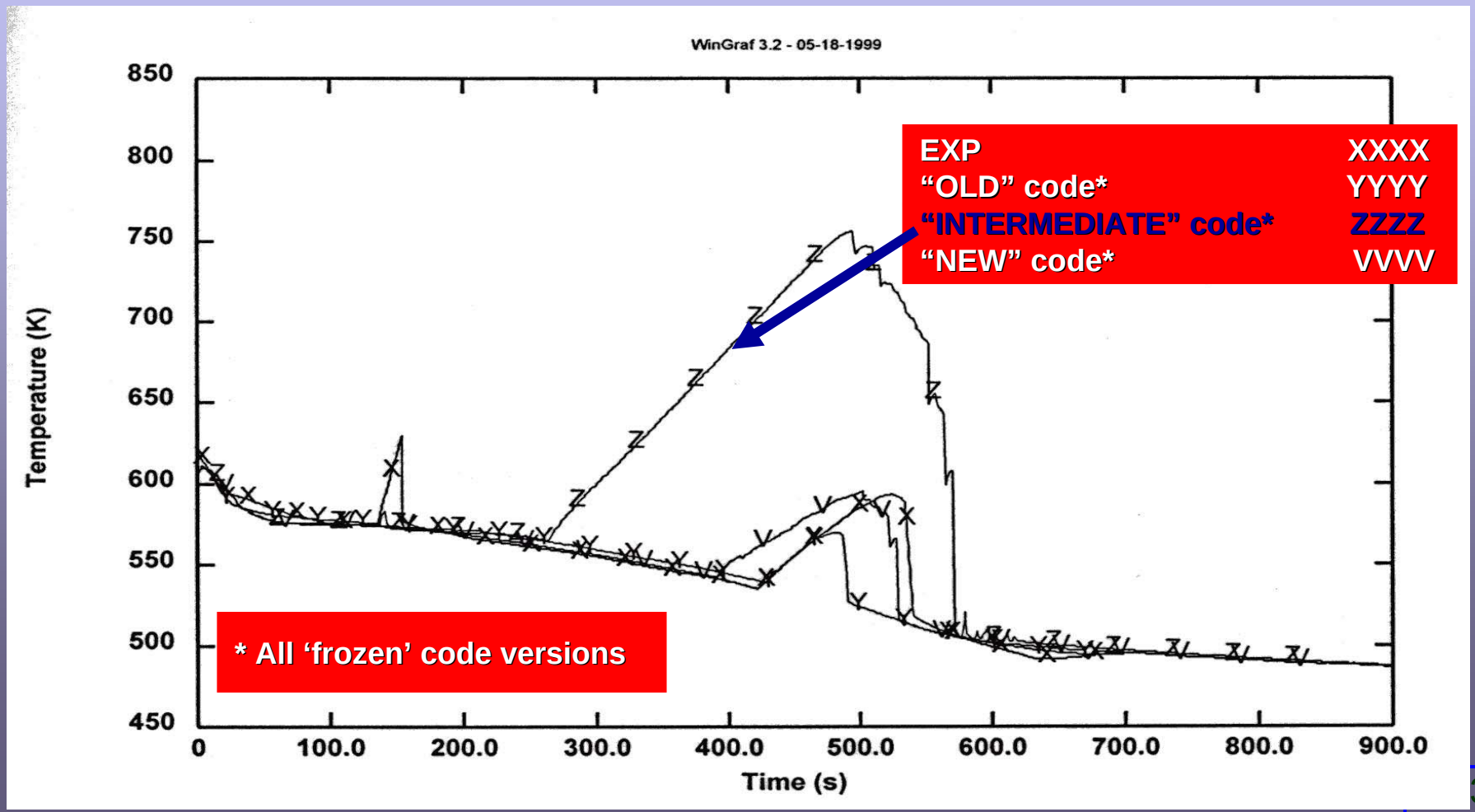
# CODE VERSIONS/SAME INPUT DECK

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

**UNIPI**
**Internal Report, 1999**



# CODE VERSIONS/SAME INPUT DECK

UNIPI
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

UNIPI
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:

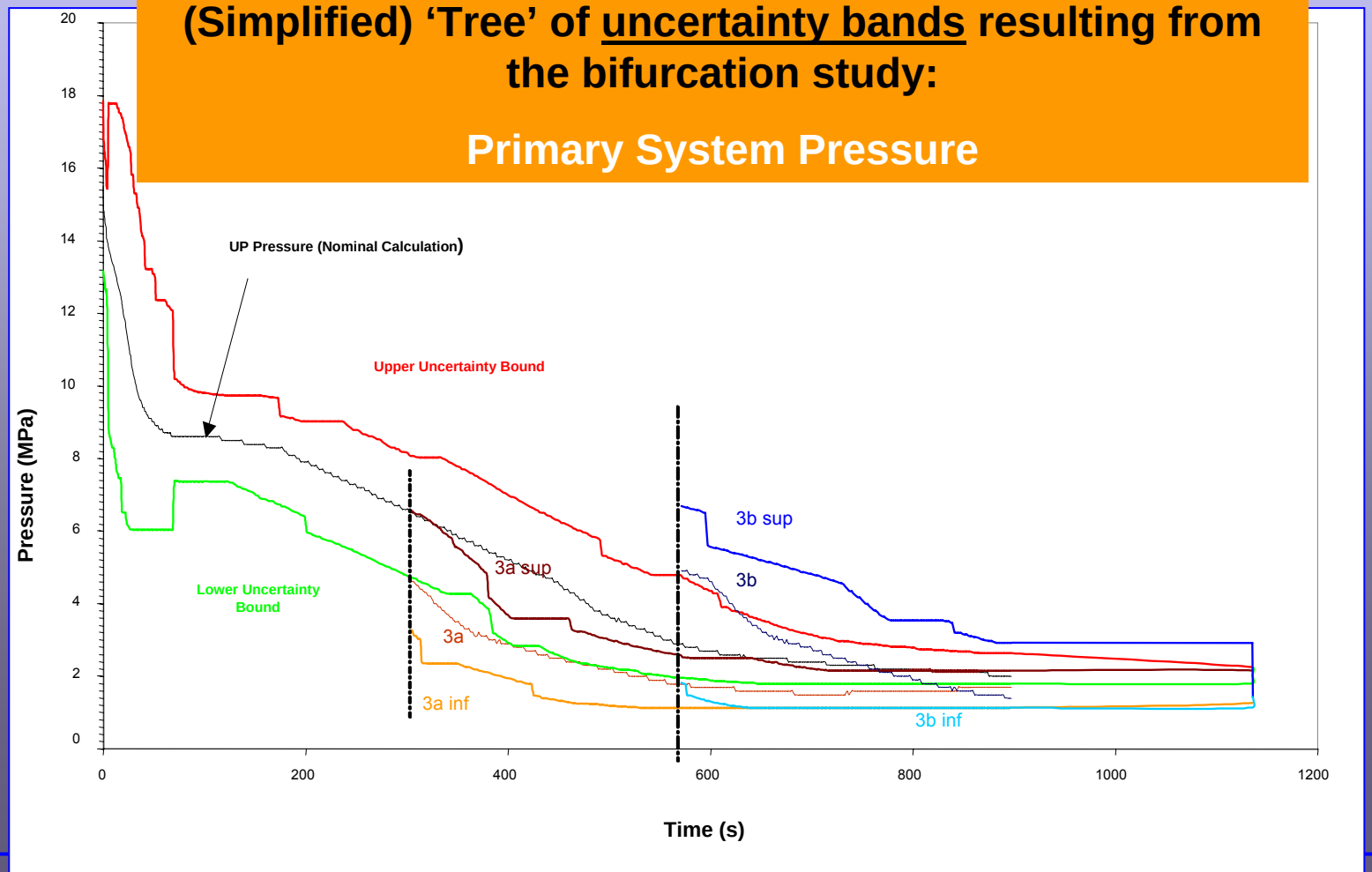
- THE IDENTIFICATION OF TYPE ONE AND OF TYPE TWO BIFURCATIONS
- THE KNOWLEDGE OF THE UNCERTAINTY CHARACTERIZING THE PARAMETERS WHICH AFFECT THE BIFURCATION.

# BIFURCATIONS

**UNIPI**
**Paper, 2000**

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

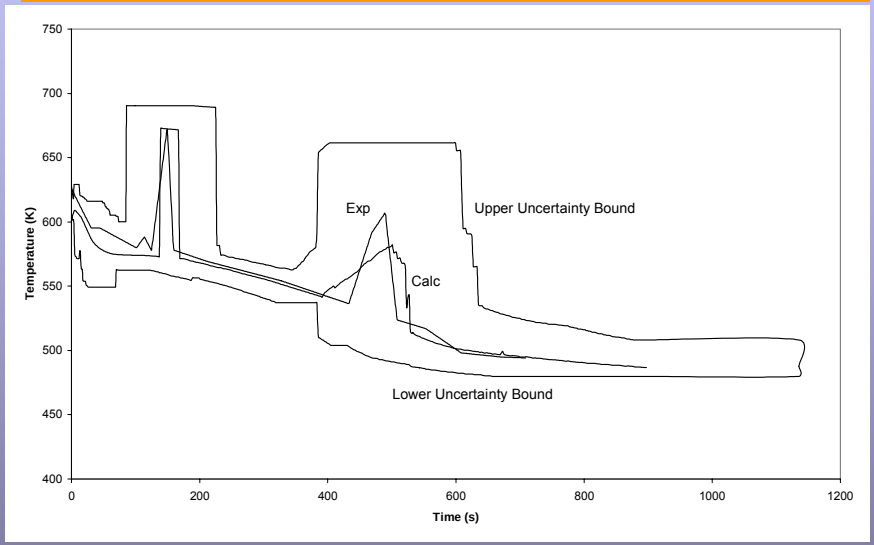
**Primary System Pressure**



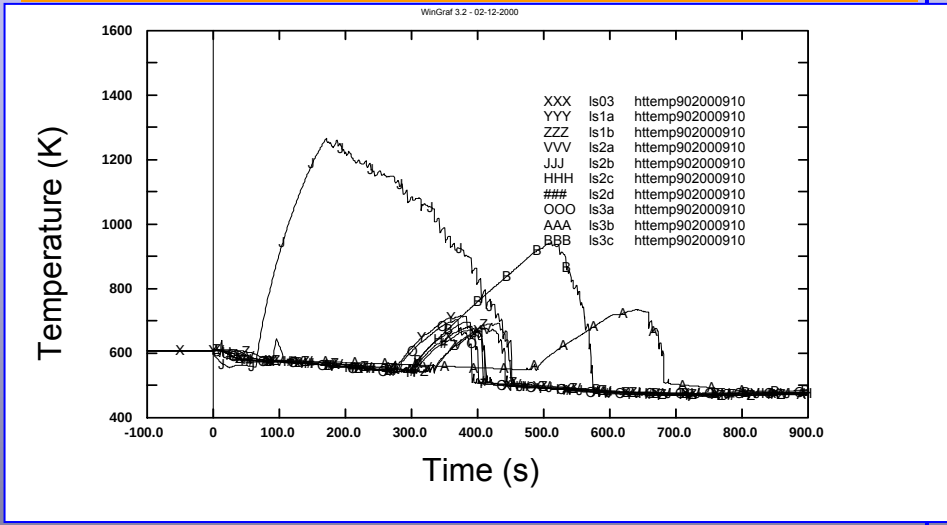
# BIFURCATIONS

**UNIPI**
**Paper, 2000**

## Standard CIAU application to UMS

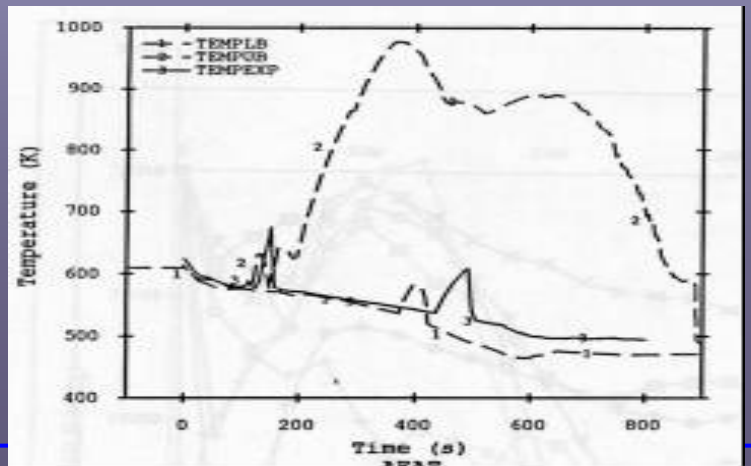



## Bifurcation CIAU boundaries for UMS




**UMS results obtained**

**By AEAT (and ENUSA)**



# BIFURCATIONS

UNIPI
Paper, 2000

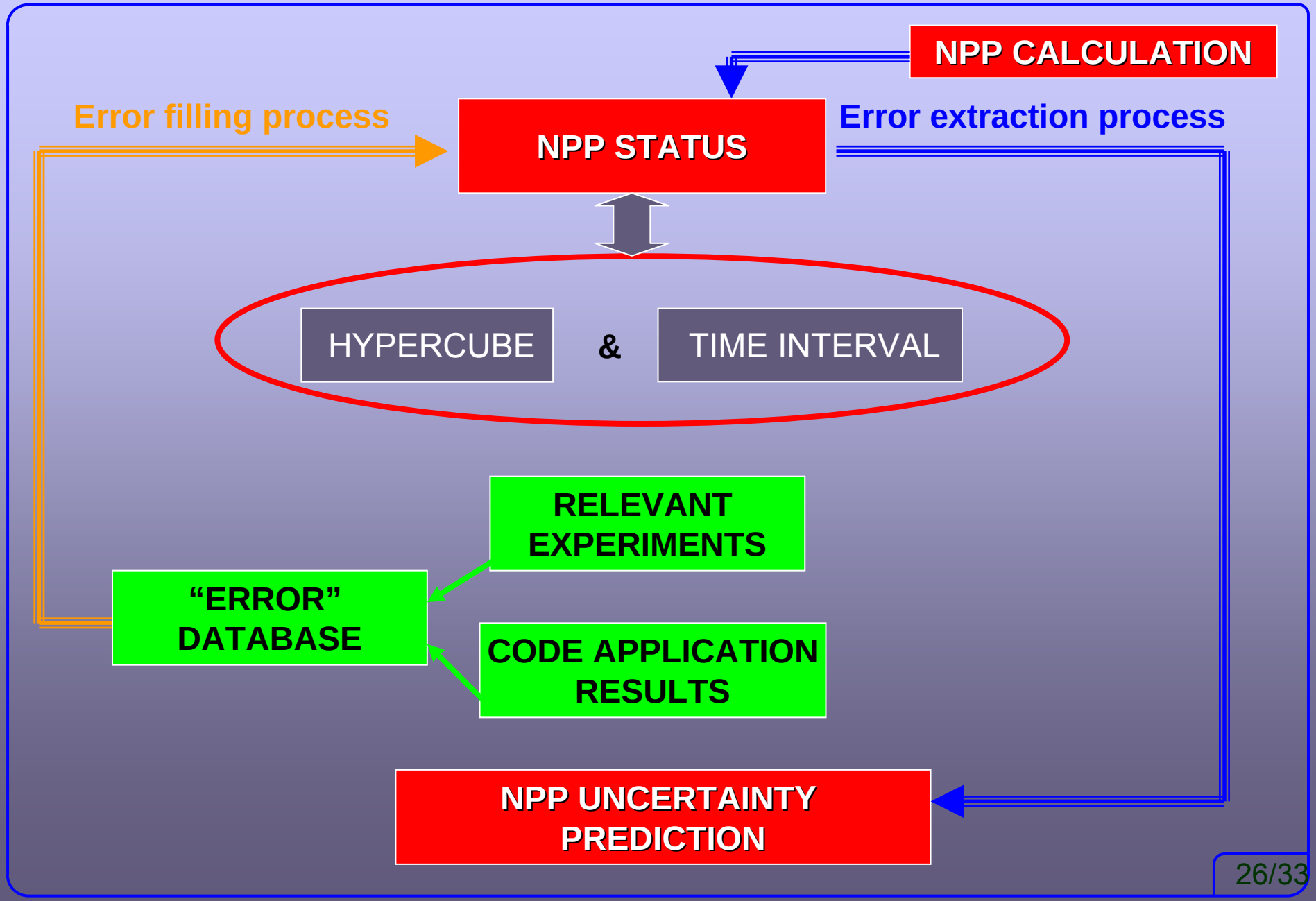
## LESSON LEARNED

BIFURCATION STUDY IS POSSIBLE

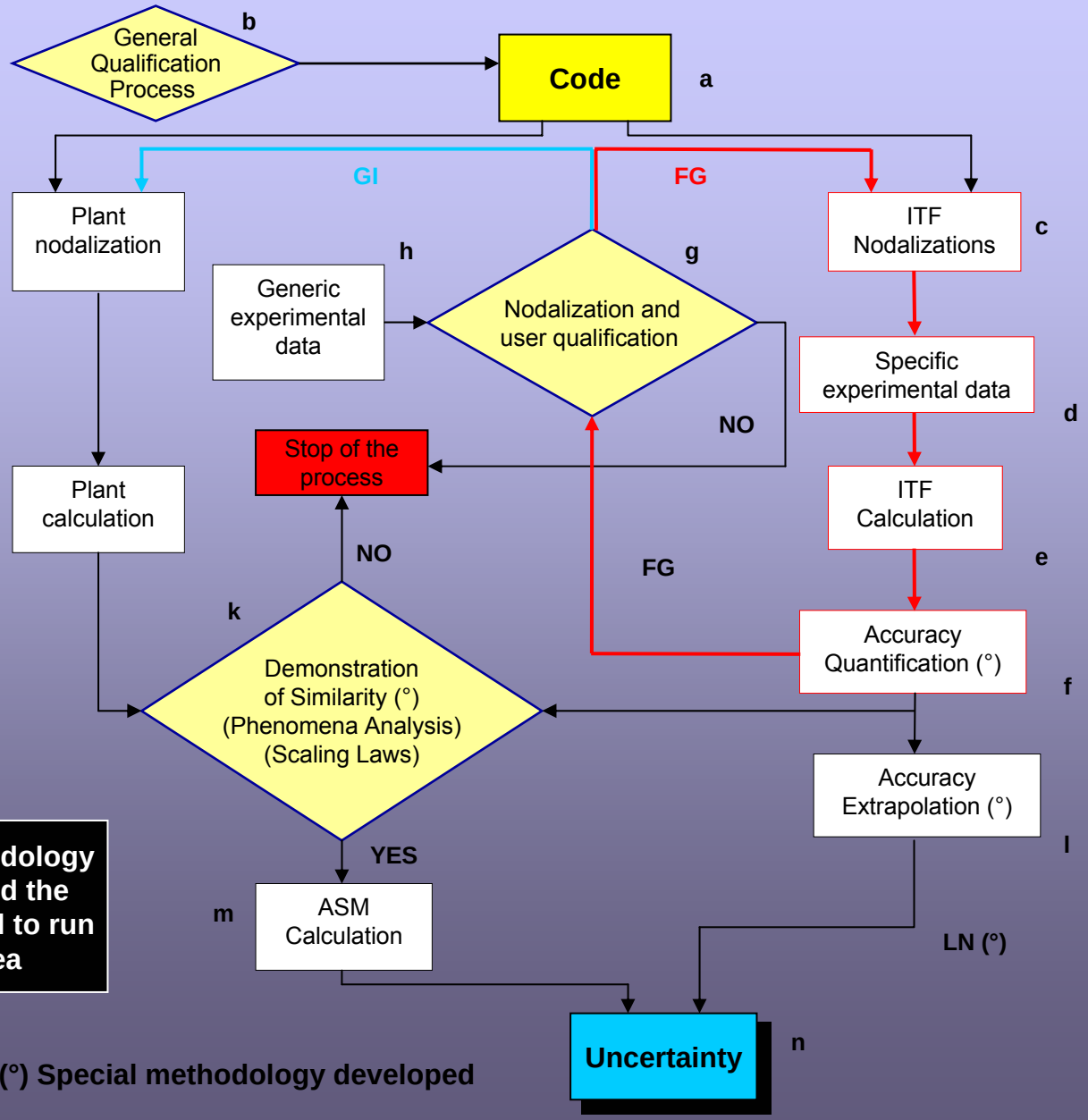
BIFURCATION STUDY PRODUCES (as expected) WIDER UNCERTAINTY BANDS (as related to the standard uncertainty study)

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

# The CIAU Method: the Idea



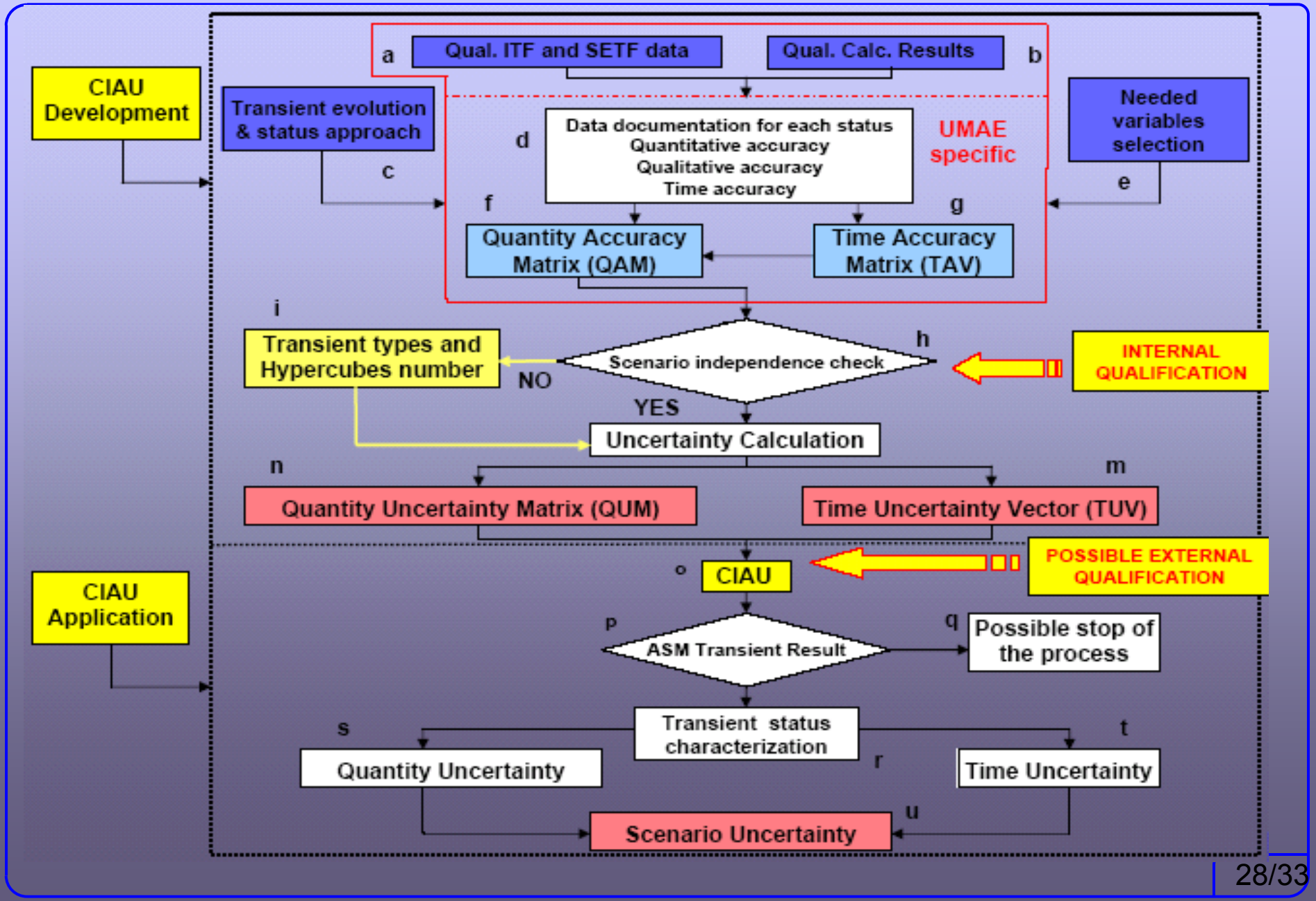
# The CIAU Method: the Engine




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

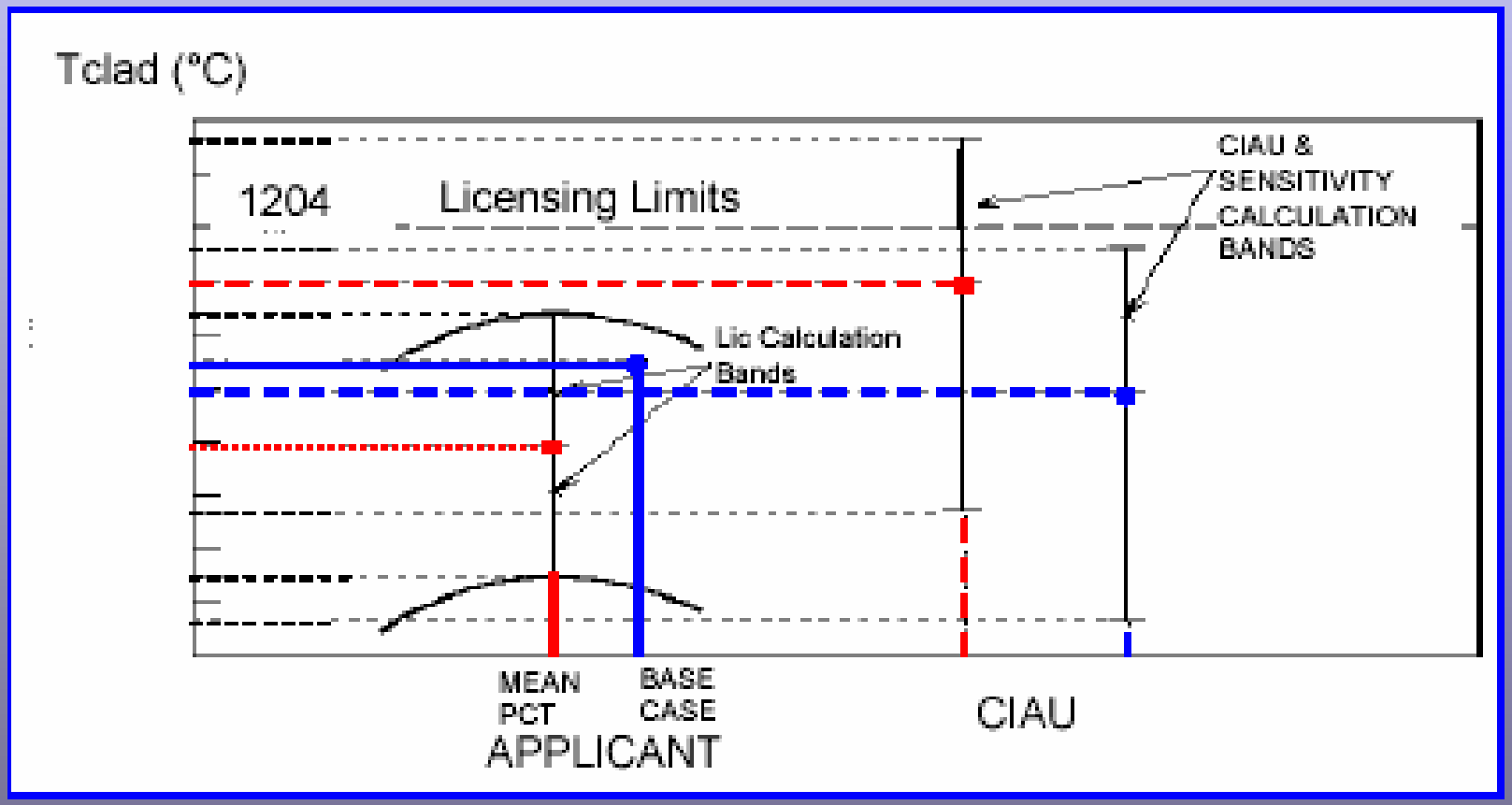
**(°) Special methodology developed**

# The CIAU Method: the Flow-Diagram



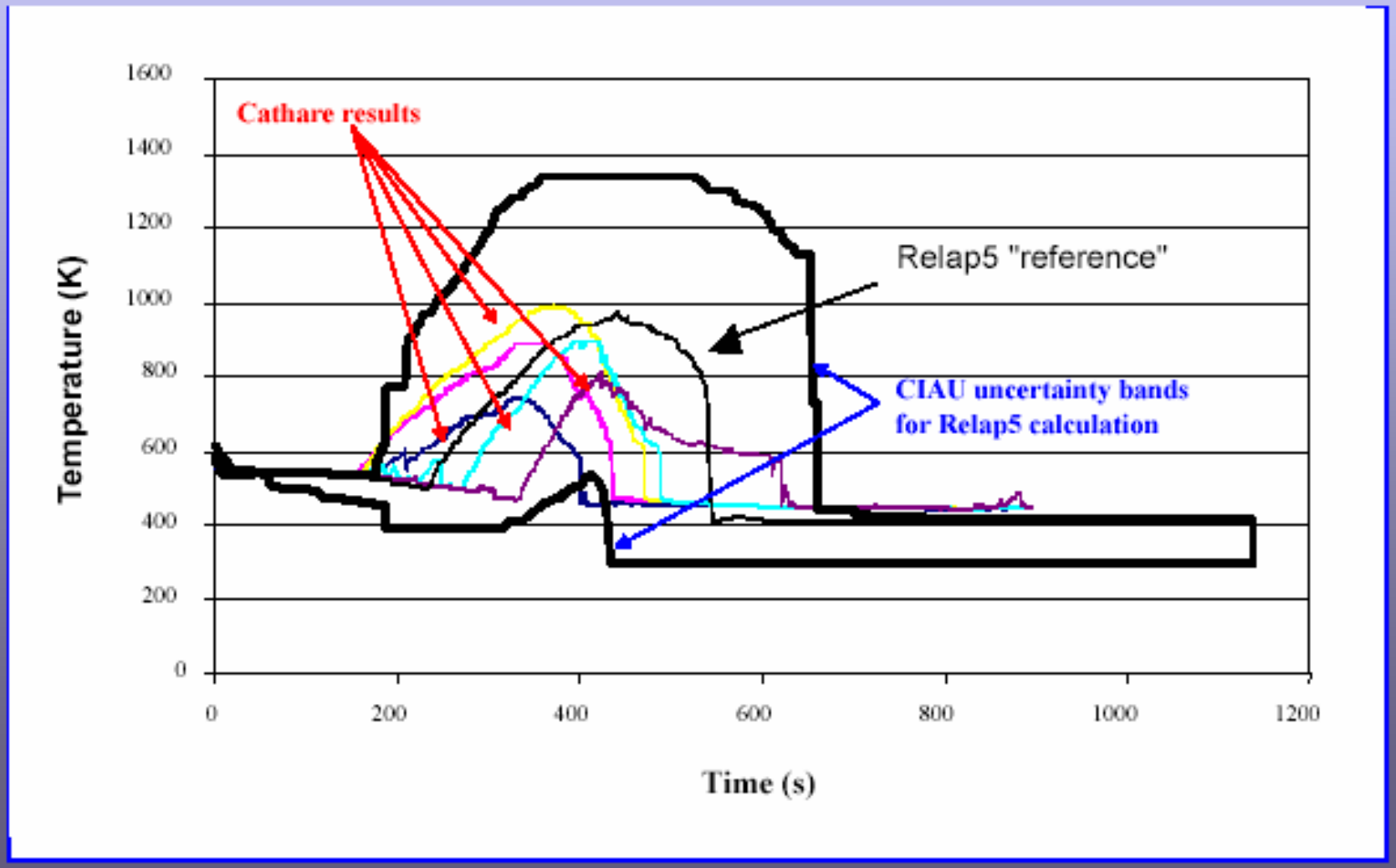
# The CIAU Method: the Application

## 1) The Angra-2 DEGB licensing calculation



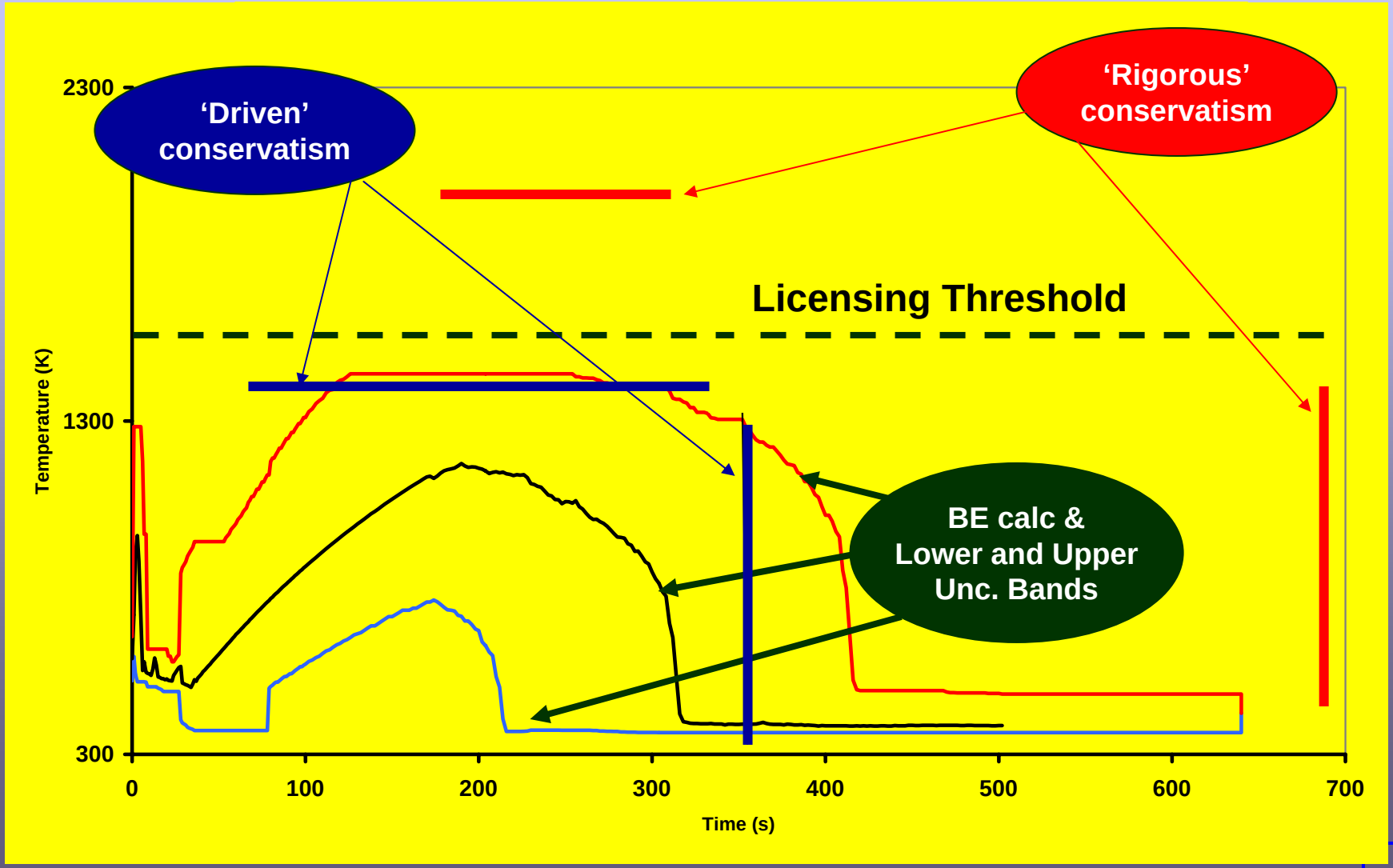
# The CIAU Method: the Application

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



# The Extension to 3D NK-TH Analysis

A 3D NK-TH RUN IMPLIES:

XSEC DERIVATION→3D NK ← →TH
(A) (B) (C) (D)(E) (F)

EACH OF THE STEPS (A) TO (F) CONSTITUTES
A SOURCE OF UNCERTAINTY

**HEREAFTER KEY RECENT FINDINGS:**

1) **APPLICATION OF GRS METHOD – PARTIAL LOFW**
2) **FINDING FROM CRISSUE-S EC PROJECT**
3) **CIAU-TN**

# The Extension to 3D NK-TH Analysis

## 1) APPLICATION OF GRS METHOD – PARTIAL LOFW

A detailed description of the plant transient and results from analyses by coupled codes can be found in Mittag, 2000 and Mittag, 2001. During a test in the Balakovo-4 VVER-1000 (Russia), one of two working main steam generator feed water pumps was switched off at nominal power. Two seconds after the pump switch-off, the power control system responded by inserting the control rod group K1 from top to bottom within four seconds. As a result, the core power decreased down to about 63 % of nominal power within 10 s. Also the control rod group K10 started moving in at a rate of 2 cm/s. The initial axial position was at 275 cm. The slow insertion of control rod group K10 down to an axial position of 140 cm resulted in a further power decrease to about 45 % of nominal power. The reactor was stabilized at this level by the automatic power control. As all four main coolant pumps continued operating, the differences between the temperatures of the hot legs and the corresponding cold legs of the four primary loops decreased proportionally to the thermal power reduction, the temperatures in the loops stabilized at a new level. Initially, the primary pressure decreased, later on the primary pressure increased again, determined by the heat balance. The transient led to a strong decrease of the water level in the pressurizer (PRZ) in the early phase, then the level increased again to nominal values.

# The Extension to 3D NK-TH Analysis

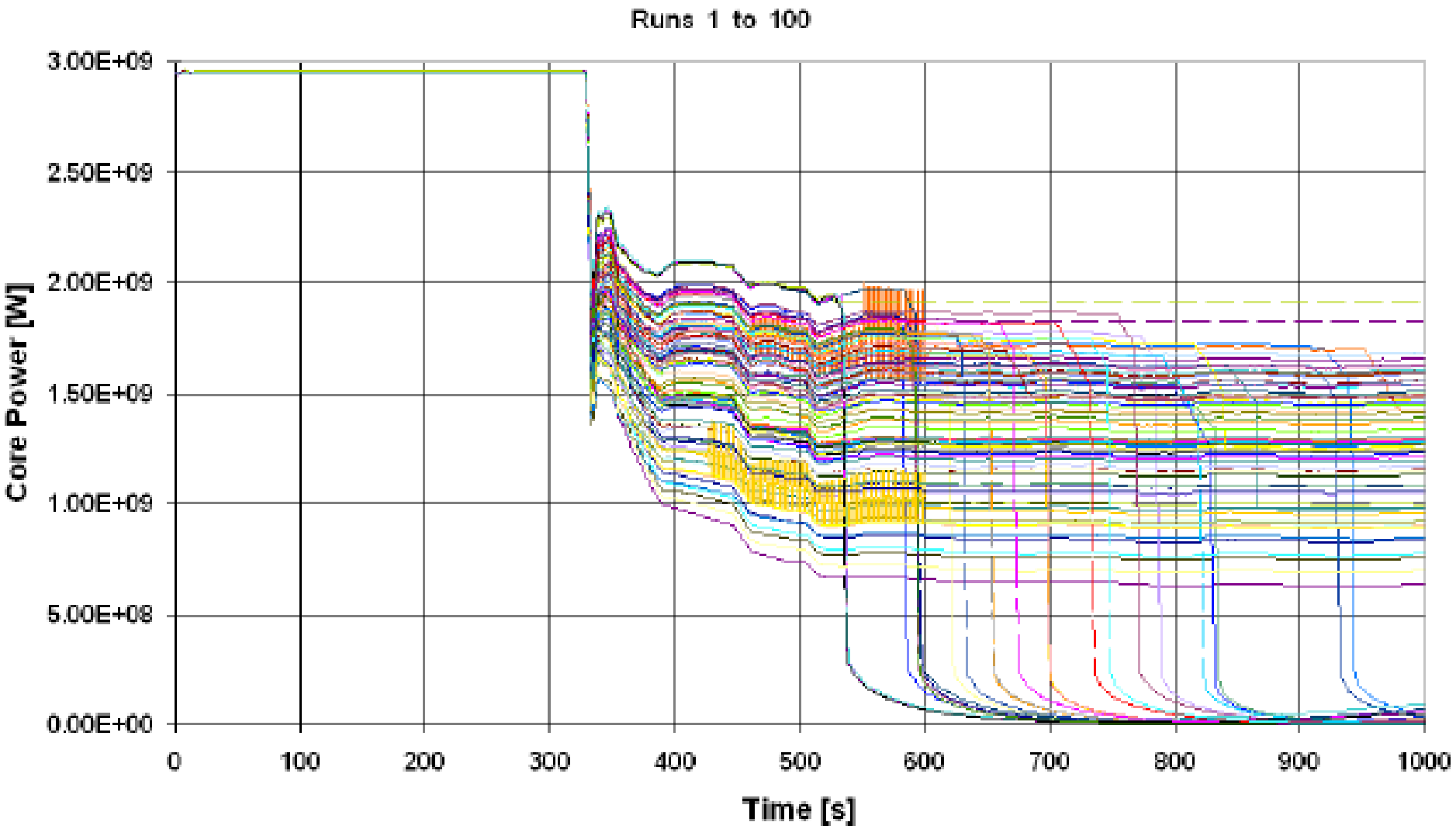
## 1) APPLICATION OF GRS METHOD – PARTIAL LOFW

**List of the identified uncertain parameters with ranges and probability distributions**

| N° | Parameter | Range | Distribution |
|---|---|---|---|
| 1 | Magnitude of secondary pressure: correction factor * | 0.9; 1.1 | uniform |
| 2 | Total reactivity worth of control rod group K1 | 0.7;1.0;1.1 | triangular |
| 3 | Total reactivity worth of control rod group K10 | 0.7;1.0;1.1 | triangular |
| 4 | Shape of axial burn-up distribution**: correction factor | 0.8;1.0 | uniform |
| 5 | Fuel temperature feedback: correction of the global core response | -0.2; 0; 0.2 (each 1/3) | discrete |
| 6 | Moderator density feedback: correction of the global core response | -0.2; 0; 0.2 (each 1/3) | discrete |
| 7 | Heaters in PRZ: heat-up time-constant [s] | 2.0; 20.0 | uniform |
| 8 | Heaters in PRZ: protection influence factor*** | 1;2 (each 1/2) | discrete |
| 9 | Fuel rod gap heat transfer coefficient [W/m²K] | 3000.0; 5000.0 | uniform |
| 10 | Mass flow of the feed water | 0.9; 1.1 | uniform |
| 11 | Enthalpy of the feed water | 0.9; 1.1 | uniform |

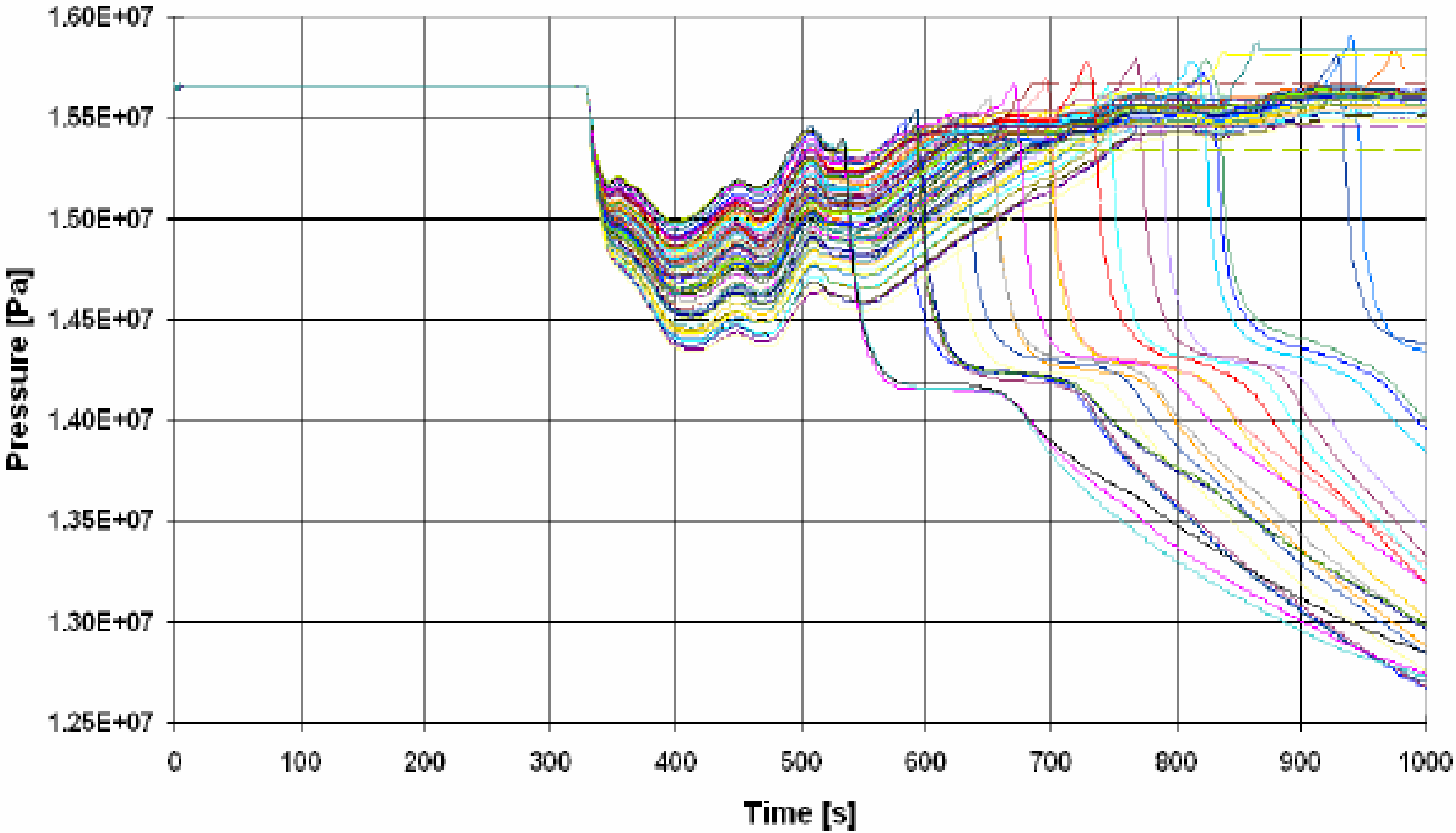
# The Extension to 3D NK-TH Analysis

## 1) APPLICATION OF GRS METHOD – PARTIAL LOFW



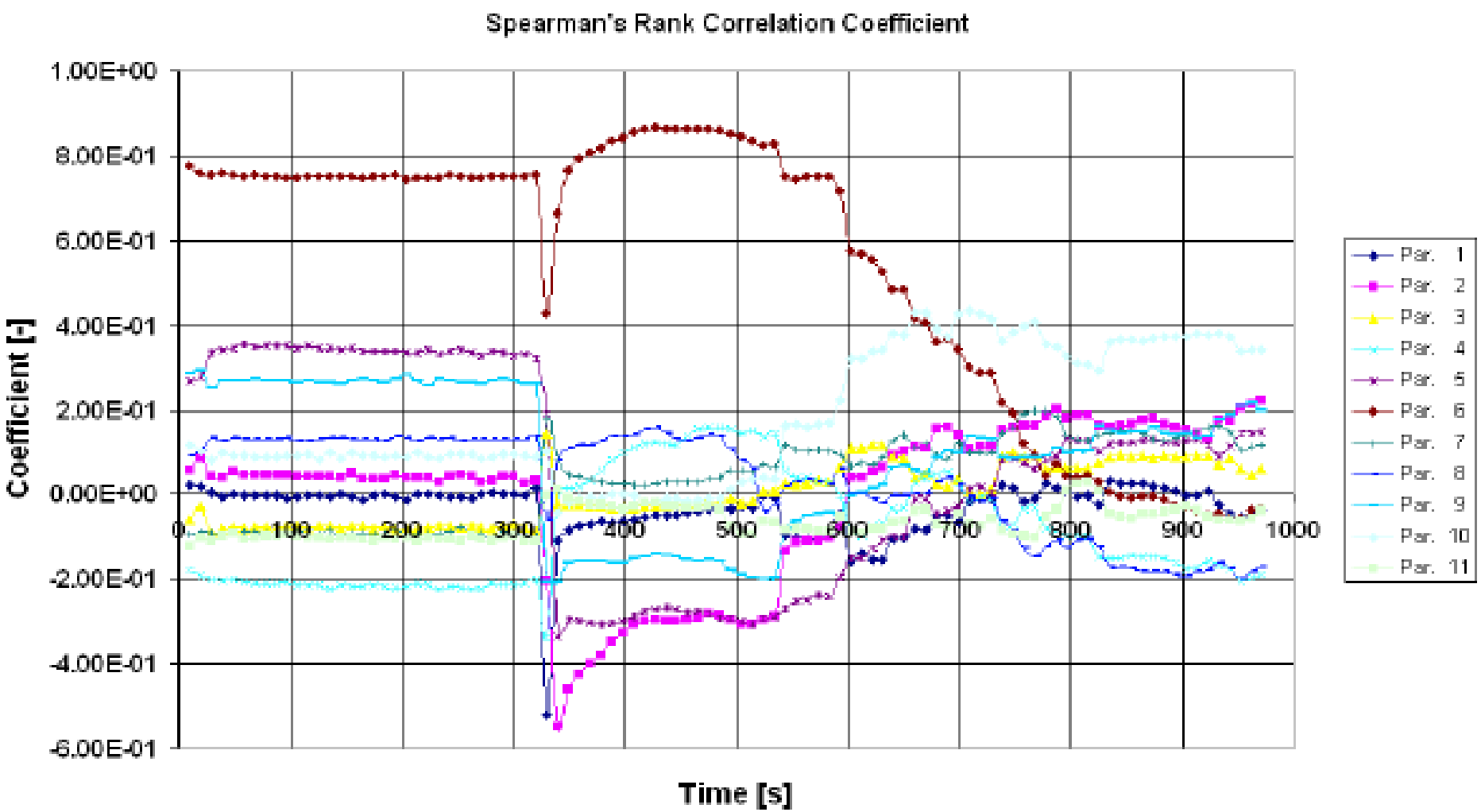
# The Extension to 3D NK-TH Analysis

## 1) APPLICATION OF GRS METHOD – PARTIAL LOFW



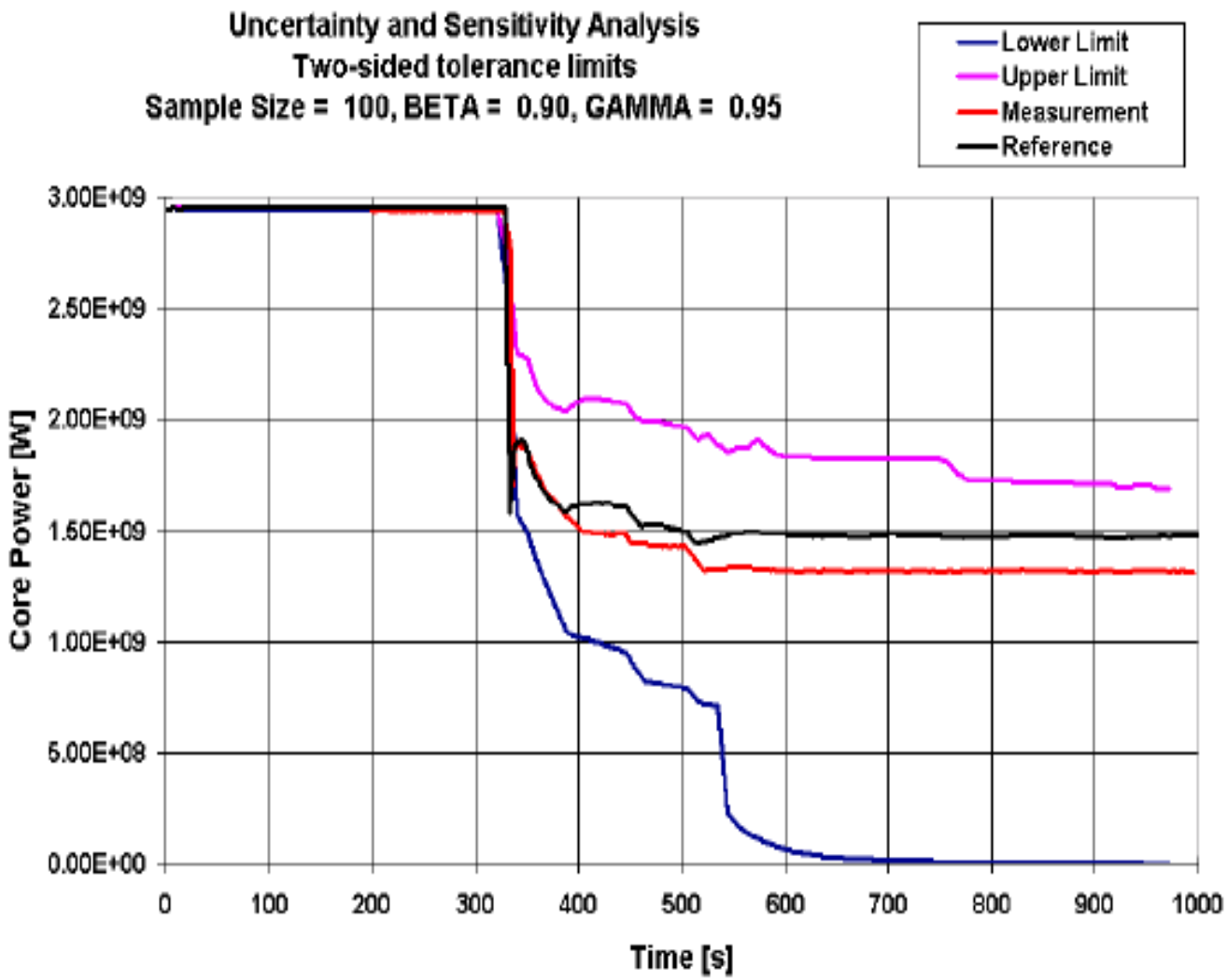
# The Extension to 3D NK-TH Analysis

## 1) APPLICATION OF GRS METHOD – PARTIAL LOFW



# The Extension to 3D NK-TH Analysis

## 1) APPLICATION OF GRS METHOD – PARTIAL LOFW



# The Extension to 3D NK-TH Analysis

## 2) FINDING FROM CRISSUE-S EC PROJECT

A variety of quantities of interest for the design and safety evaluation of LWR are the output of coupled 3-D neutron kinetics/thermal-hydraulics calculation. These range from the $k_{eff}$, to the boron concentration to reach criticality, to the worth of CR, to the transient pressure, the fuel temperature, the flow rate, the level (*e.g.* in the PRZ), the amount of radioactive liquid discharged from a relief valve (SRV or PORV). The identification of these quantities is connected with the transient type (*e.g.* ATWS or LBLOCA), with the application type, notably licensing or design analysis and is related to the duration of the transient. Each application is definitely associated with a set of quantities of interest. A minimum reasonable set of quantities of interest is defined below, making reference to a transient duration of the order of 100 s. The following quantities are selected and related point values are considered:

# The Extension to 3D NK-TH Analysis

## 2) FINDING FROM CRISSUE-S EC PROJECT

- [Quantity 1 and 2]. Peak pressure in RPV (UP location) and in PRZ (if applicable), related FWHM (if applicable) and time of occurrence.
- [Quantity 3]. Peak total core power, related FWHM (if applicable) and time of occurrence.
- [Quantity 4]. CHF (or DNB) occurrence time.
- [Quantity 5]. PCT and time of occurrence.
- [Quantity 6]. Maximum fuel temperature (MFT) and time of occurrence.
- [Quantity 7]. Total thermal energy released to the fluid (TTEF) during the transient.
- [Quantity 8]. Maximum % of core, in terms of heat transfer area (HTA) of the active region where, at any time, rod surface temperature > 1 000 K occurs (CRHST = core region at high surface temperature).
- [Quantity 9]. Maximum % of core in terms of volume occupied by fuel pins in the active region where, at any time, fuel temperature > 3 000 K occurs (CRHFT = core region at high fuel temperature).

# The Extension to 3D NK-TH Analysis

## 2) FINDING FROM CRISSUE-S EC PROJECT

- [Quantity error, situation 'a']. For core power pulses characterised by FWHM < 0.1 s in the reference BE evaluation, the acceptable threshold error is 100% nominal power or 300% initial power of the considered system, which ever is smaller.

- [Quantity error, situation 'b']. For core power pulses characterised by FWHM ≥ 0.1 s in the reference BE evaluation, the acceptable threshold error is 20% nominal power or 100% initial power of the considered system, which ever is smaller.

# The Extension to 3D NK-TH Analysis

## 2) FINDING FROM CRISSUE-S EC PROJECT

- [Quantity error, situation 'b']. For PCT, the acceptable threshold error is 150 K (larger errors can be tolerated for BE prediction of PCT below 1 000 K).
- [Quantity error, situation 'b']. For MFT, the acceptable threshold error is 200 K.
- [Quantity error]. For TTEF the acceptable threshold error is 10% of energy released to the fluid in nominal conditions or 100% of energy released to the fluid at the actual initial power, during the considered transient duration, which ever is smaller.
- [Quantity error]. For CRHST the acceptable threshold error is 10% of core HTA.
- [Quantity error]. For CRHFT the acceptable threshold error is 10% of core pin volume.
- [Time error, situation 'a']. The acceptable time error that can be associated to the prediction of time of occurrence of Quantities 1 to 3 is 100% of the BE value.
- [Time error, situation 'b']. The acceptable time error that can be associated to the prediction of time of occurrence of Quantities 1 to 6 is 20% of the BE value.
- [Time error, situations 'a' and 'b']. The acceptable time error that can be associated to the prediction of FWHM for Quantities 1 to 3 is 20% of the BE value.

# The Extension to 3D NK-TH Analysis

## 2) FINDING FROM CRISSUE-S EC PROJECT

*Acceptability thresholds for the quantities of interest*

The definition of acceptability thresholds encounters the same difficulties mentioned earlier as concerns the quantities of interest. The dimension of the core, including the nominal power, the power generated per unit volume and various other nominal operating conditions (*e.g.* nominal pressure, set point for valves opening) may also affect the identification of thresholds of acceptance.

However, the errors that are acceptable (acceptability thresholds) for the identified quantities are defined here. In the present approach it is assumed that the overall error for a point-value quantity is the combination of two independent contributions: the quantity errors and the time error. Therefore, the predicted point-value quantity stays in a rectangle whose geometric centre is the BE prediction and whose edges are given by the "quantity" and the "time" error values [7].

# The Extension to 3D NK-TH Analysis

## 3) CIAU-TN

- EXTENSION OF THE CIAU UNCERTAINTY ANALYSIS TO THE (3D) CORE POWER → **CIAU-TN**
- CIAU-TN IS BASED UPON THE SAME APPROACH OF CIAU FOR THERMAL-HYDRAULICS CODES
- **TOTAL REACTIVITY** AND **CORE AVERAGE EXPOSURE** ARE 'NEW' DRIVING QUANTITIES:

| Driving Quantities | | (1) Upper Plenum Pressure (MPa) | (2) Primary Circuit Mass Inventory (%)[a] | (3) Steam Generator Pressure (MPa) | (4) Cladding Temperature at 2/3 Core Height (K) | (5) Steam Generator Level (%)[a] | (6) Core Power (%)[a] | (7) Total Reactivity (dk/k) | (8) Core Average Exposure (GWd/t) |
|---|---|---|---|---|---|---|---|---|---|
| Hypercube Limits | 1 | 0.09 – 0.5 | 10 – 40 | 0.1 – 3.0 | 298 – 473 | 0 – 50 | 0.5 – 1.0 | 0.0070 – 0.0050 | 0 – 10 |
| | 2 | 0.5 – 2.0 | 40 – 80 | 3.0 – 7.0 | 473 – 573 | 50 – 100 | 1.0 – 6.0 | 0.0050 – 0.0030 | 10 – 20 |
| | 3 | 2.0 – 4.0 | 80 – 100 | 7.0 – 9.0 | 573 – 643 | 100 – 150 | 6.0 – 50 | 0.0030 – 0 | 20 – 30 |
| | 4 | 4.0 – 5.0 | 100 – 120 | - | 643 – 973 | - | 50 – 100 | 0 – -0.010 | 30 – 40 |
| | 5 | 5.0 – 7.0 | - | - | 973 – 1473 | - | 100 – 130 | -0.010 – -0.100 | - |
| | 6 | 7.0 - 9.0 | - | - | - | - | 130 – 300 | -0.100 – -0.400 | - |
| | 7 | 9.0 – 10.0 | - | - | - | - | 300 – 1000 | - | - |
| | 8 | 10.0 – 15.0 | - | - | - | - | 1000 - $10^6$ | - | - |
| | 9 | 15.0 – 18.0 | - | - | - | - | - | - | - |

[a] Percent of the initial nominal value.

# The Extension to 3D NK-TH Analysis

**3) CIAU-TN**

• 'NEW' UNCERTAINTY VECTORS ARE INTRODUCED

- **DTUV** (Detailed Time Uncertainty Vector) → *uncertainty on the time when the power peak occurs*
- **DPUV** (Detailed Power Uncertainty Vector) → *uncertainty on the quantity of the Core Power*
- **APFUV** (Axial Peaking Factors ($F_z$) Uncertainty Vector) → *uncertainty on the quantity of Fz*
- **ZUV** (Axial (Z) Position Uncertainty Vector) → *uncertainty on axial position of the maximum value of Fz*
- **RPFUV** (Radial Peaking Factors ($F_R$) Uncertainty Vector) → *uncertainty on the quantity of $F_R$*
- **XUV**, **YUV** (Radial (X,Y) Position Uncertainty Vector) → *uncertainty on radial (x, y) position of the maximum value of $F_R$*

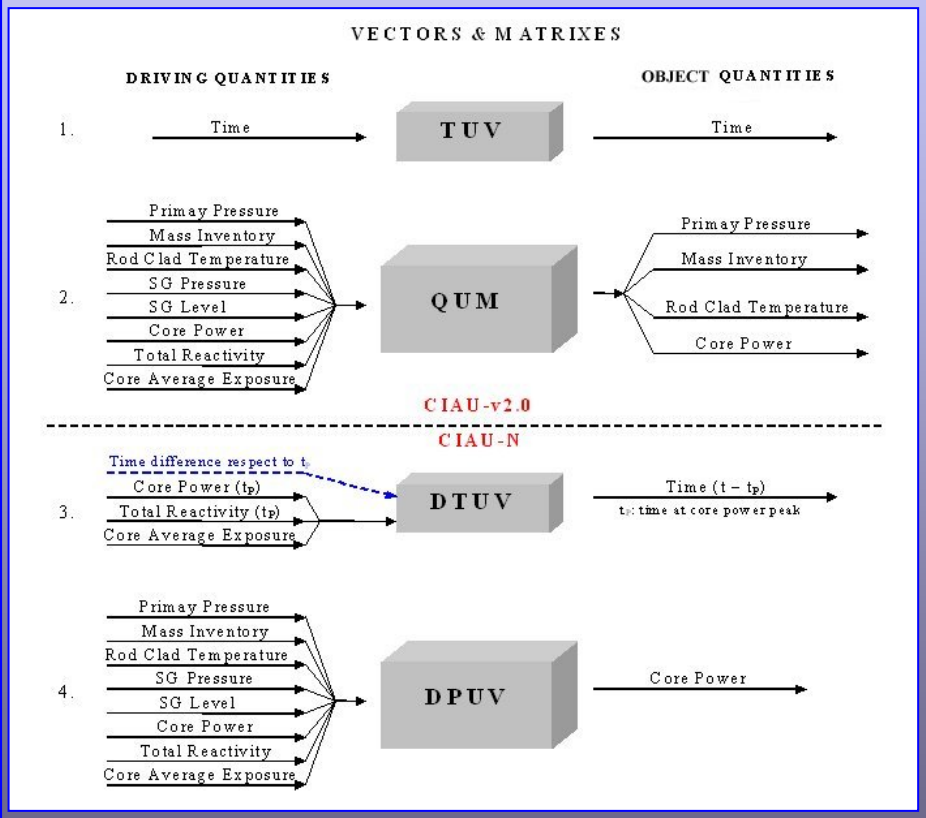
• 'NEW' OBJECT QUANTITIES

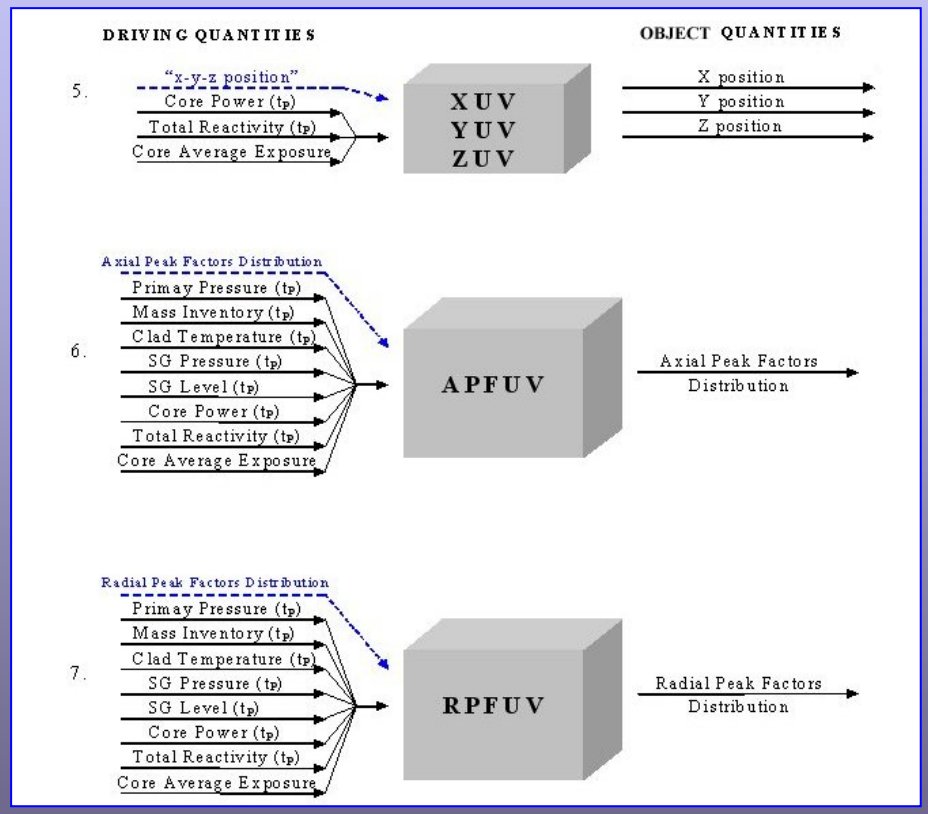
- CORE POWER HYSTORY
- AXIAL PEAKING FACTORS DISTRIBUTION
- AVERAGE RADIAL PEAKING FACTORS DISTRIBUTION

# The Extension to 3D NK-TH Analysis

**3) CIAU-TN**

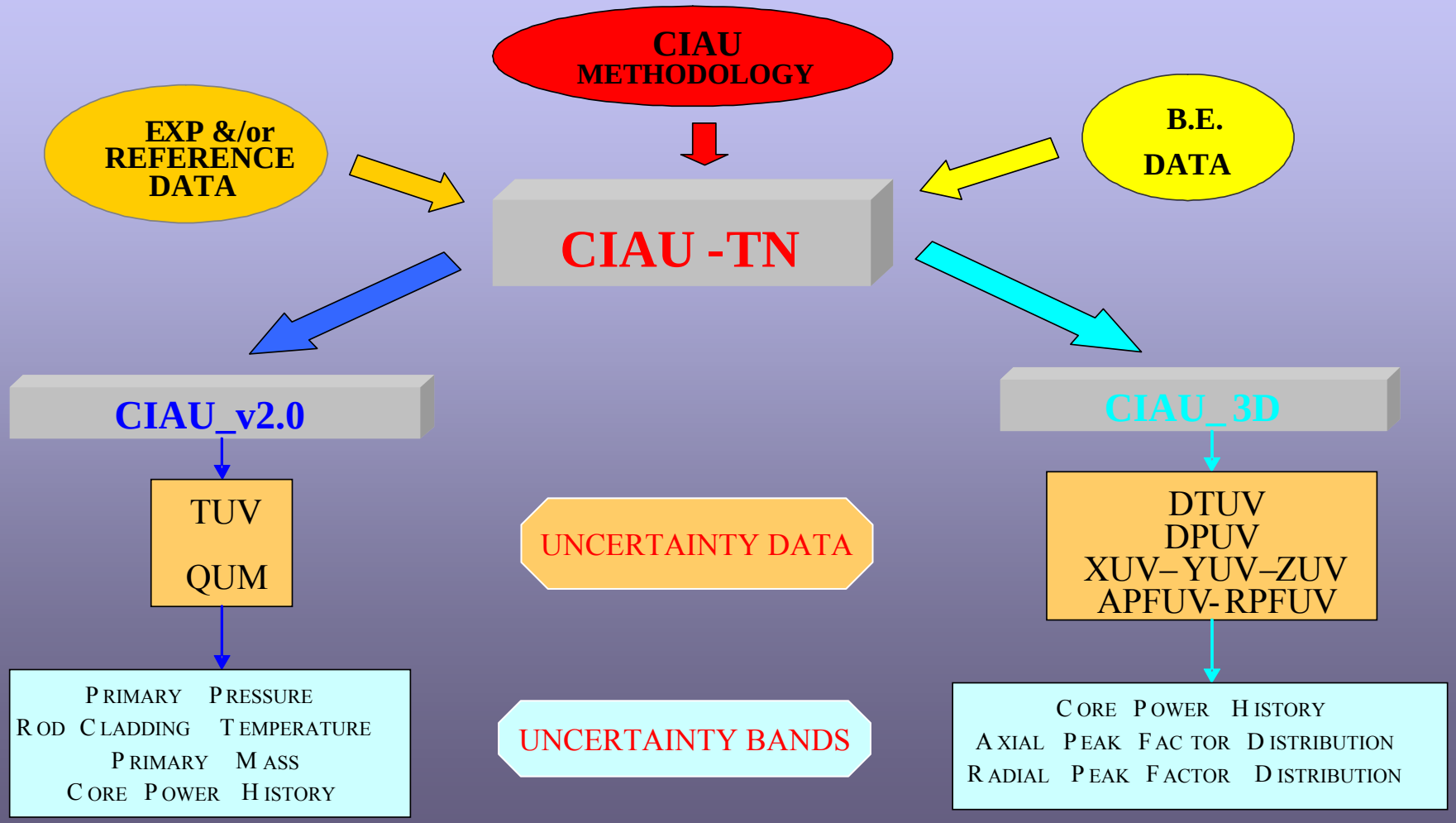
## STRUCTURES OF UNCERTAINTY MATRICES & VECTORS



3) CIAU-TN

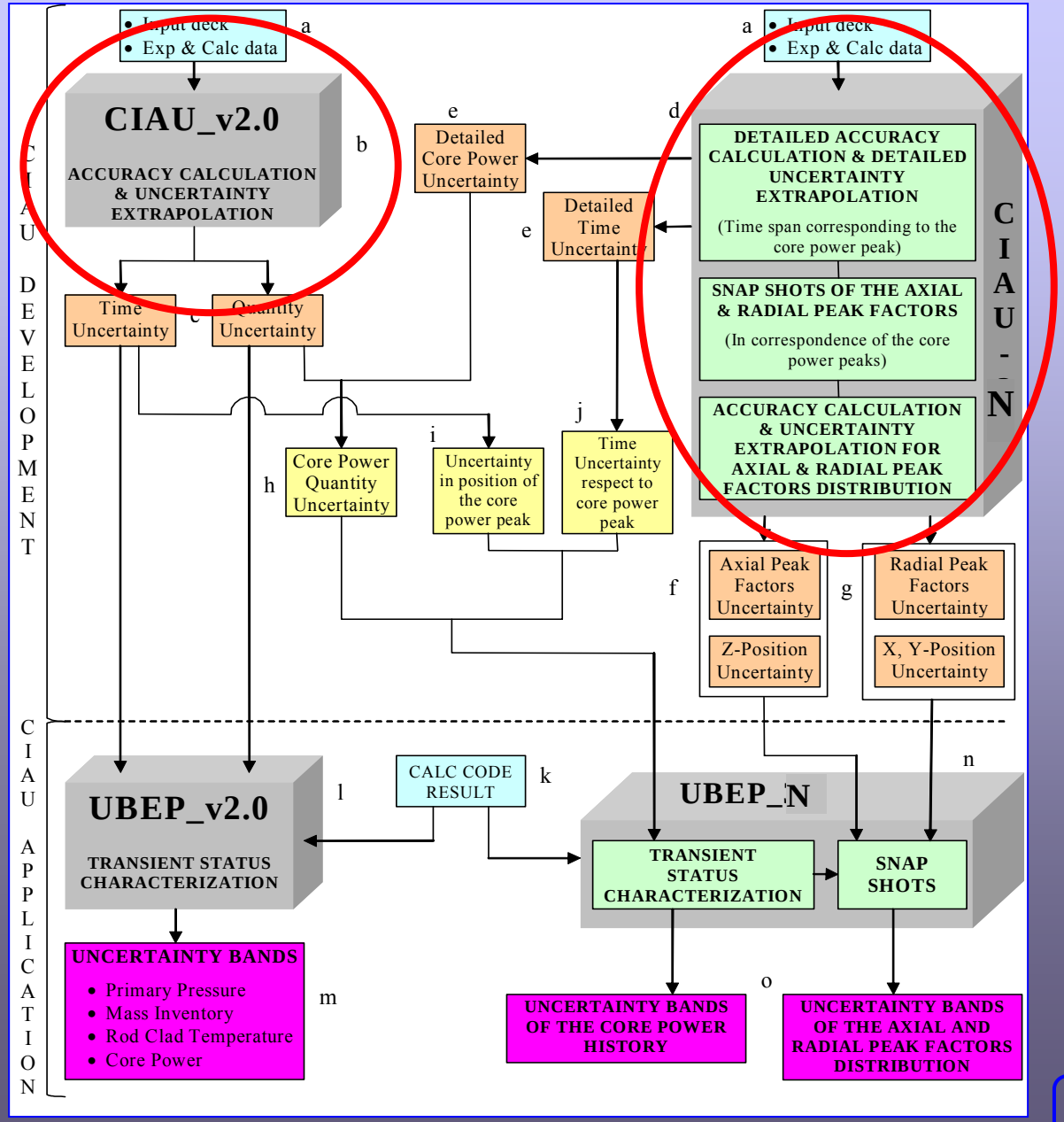
# CIAU-TN: Simplified Diagram



# The Extension to 3D NK-TH Analysis

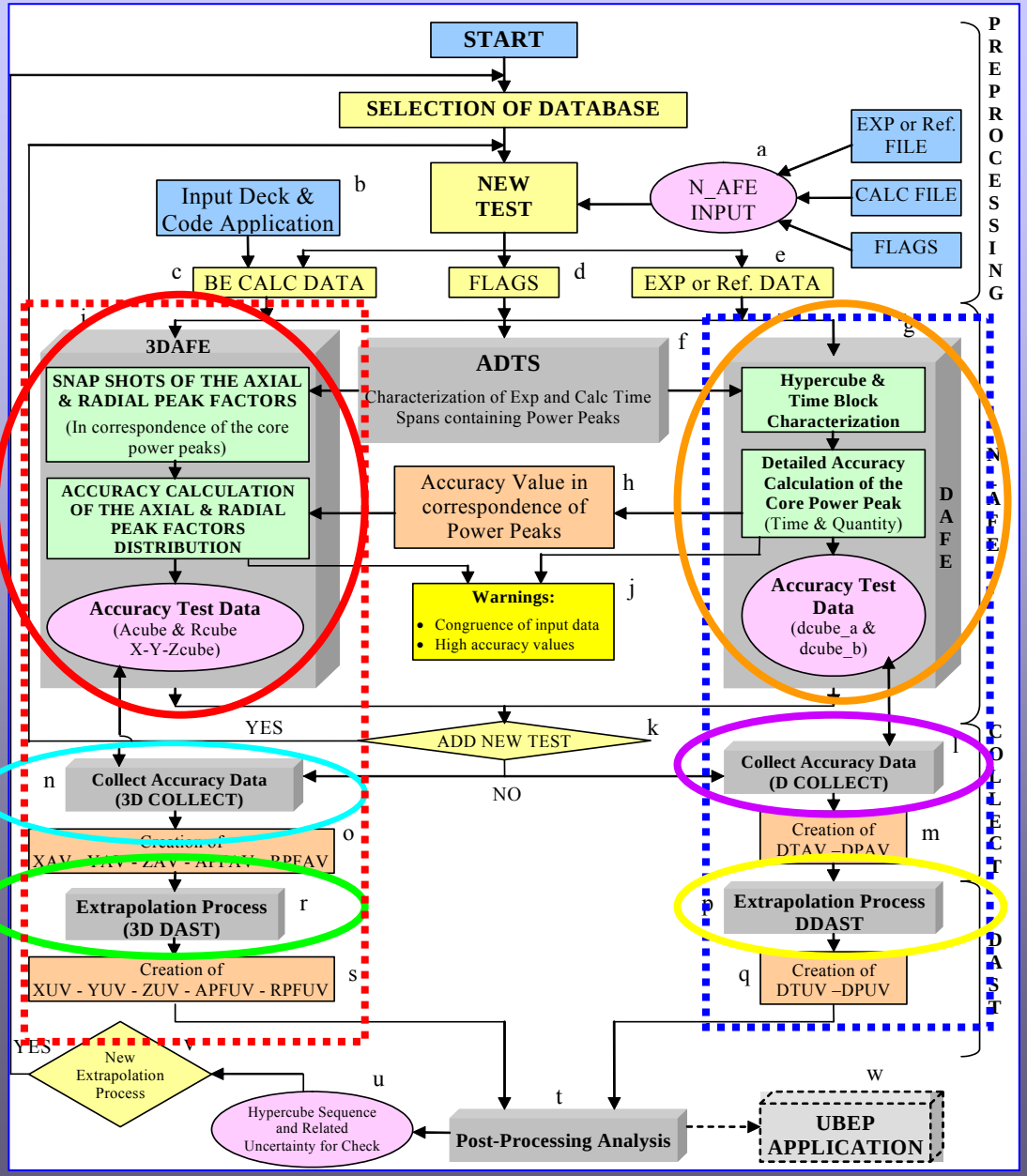
**3) CIAU-TN**

## CIAU-TN DIAGRAM



# The Extension to 3D NK-TH Analysis

3) CIAU-TN




## CIAU-N TOOLS

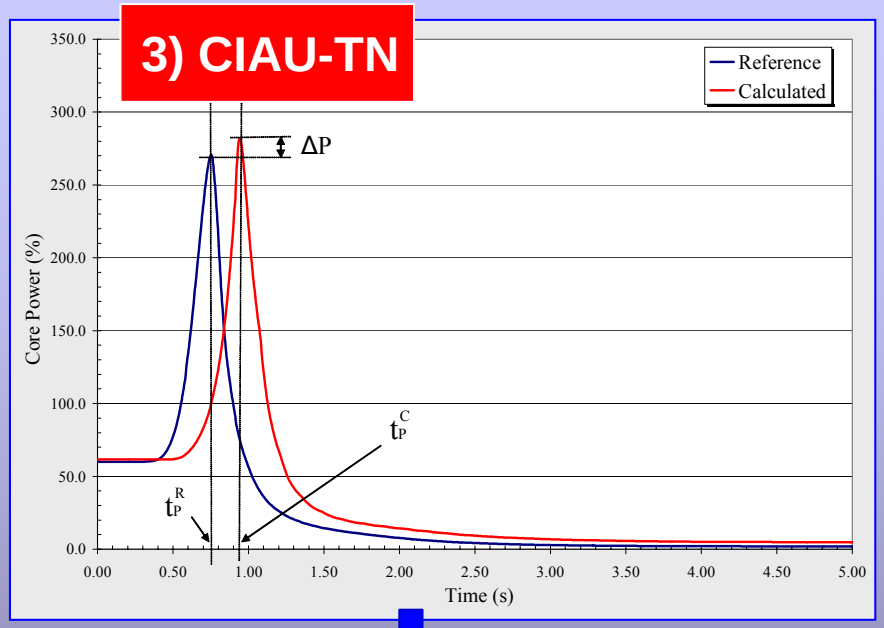
**SPATIAL ANALYSIS TOOL:**

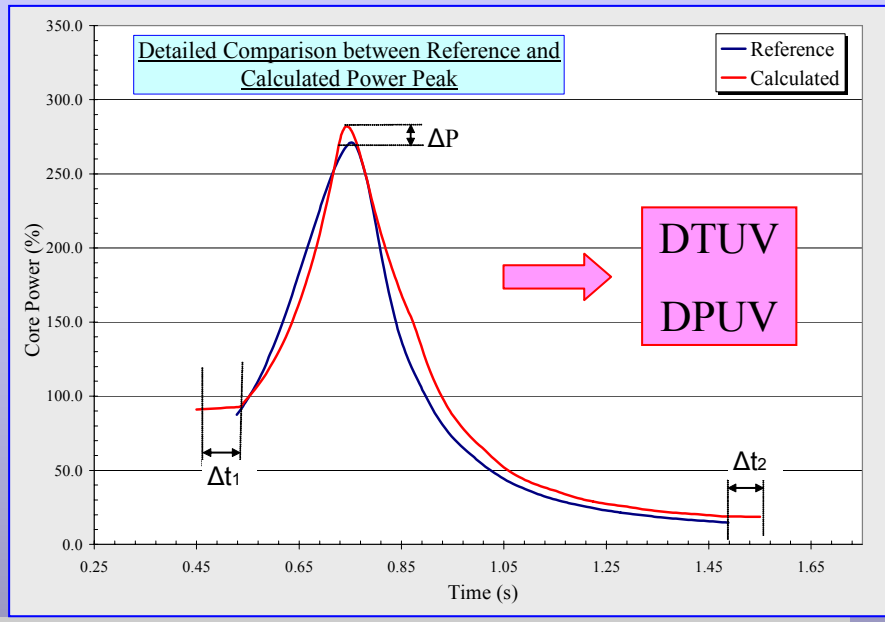
- 3D-AFE
- 3D-COLLECT
- 3D-DAST

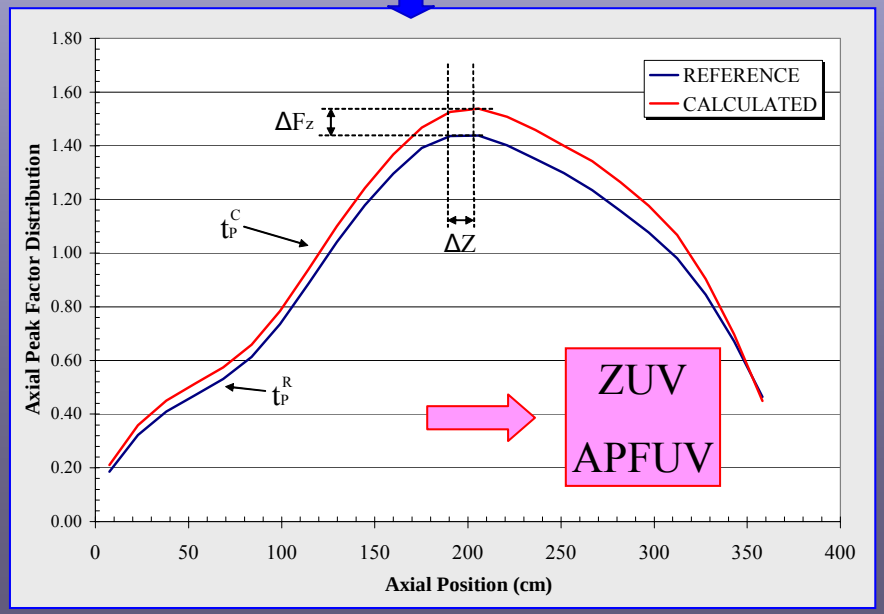
**TIME ANALYSIS TOOL:**

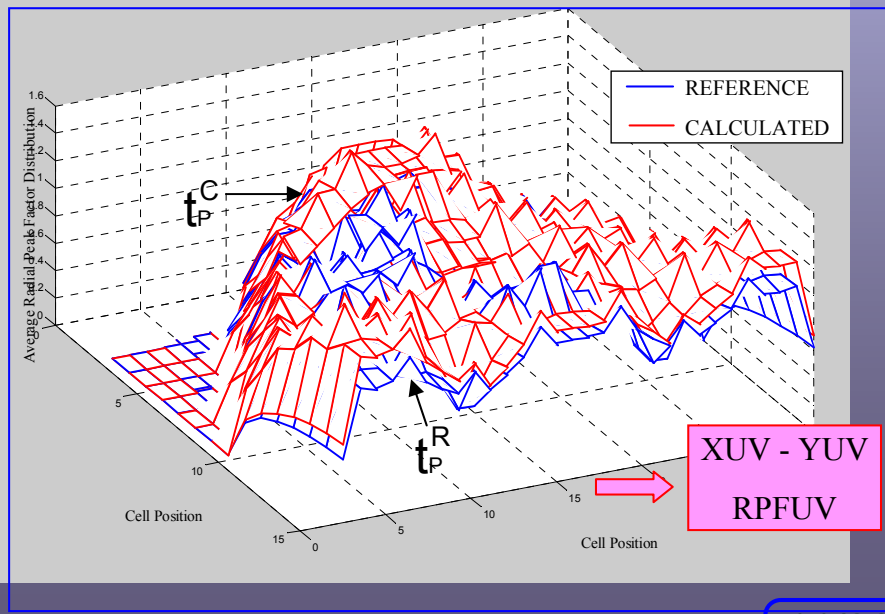
- D-AFE
- D-COLLECT
- D-DAST

# The Extension to 3D NK-TH Analysis



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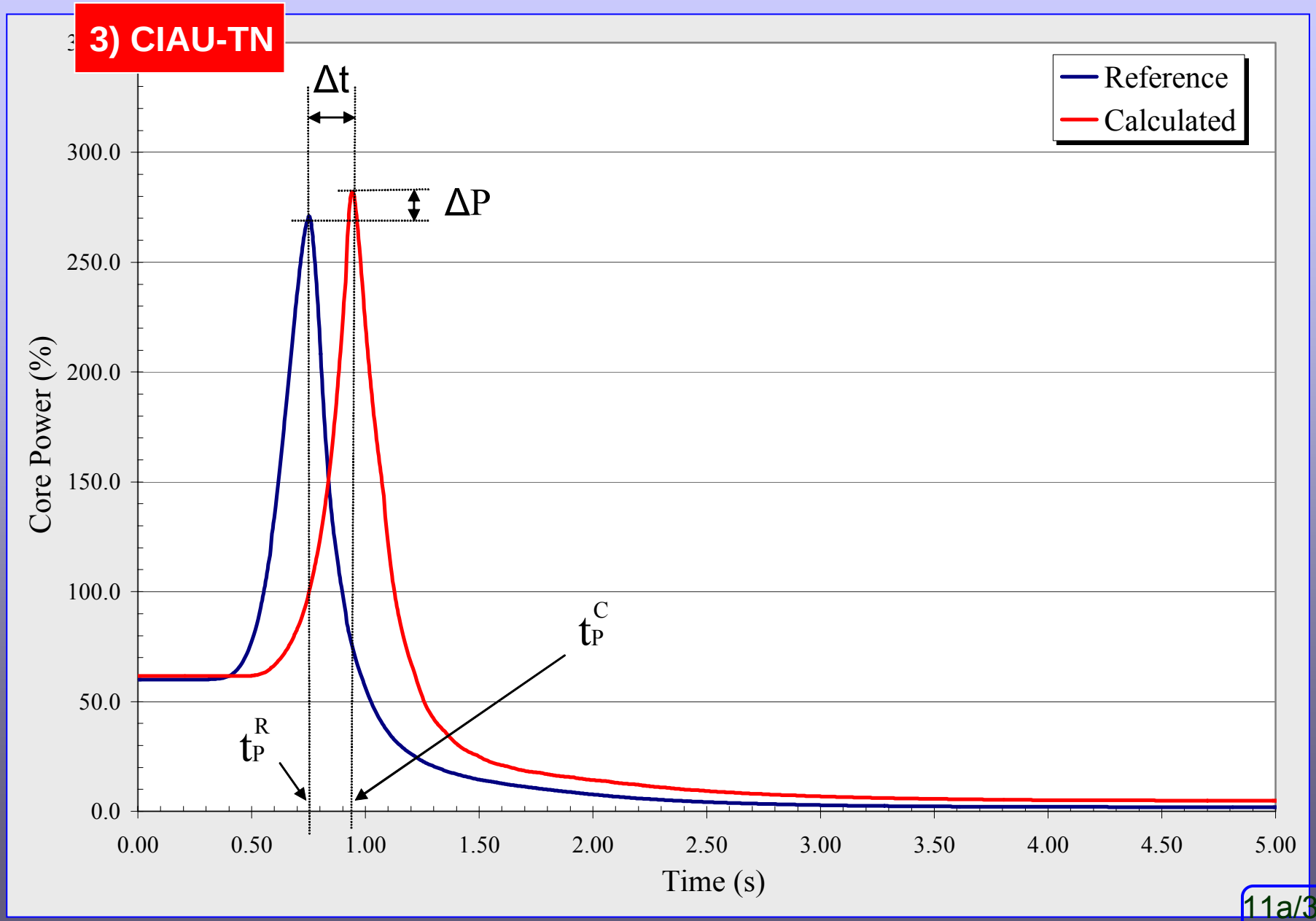
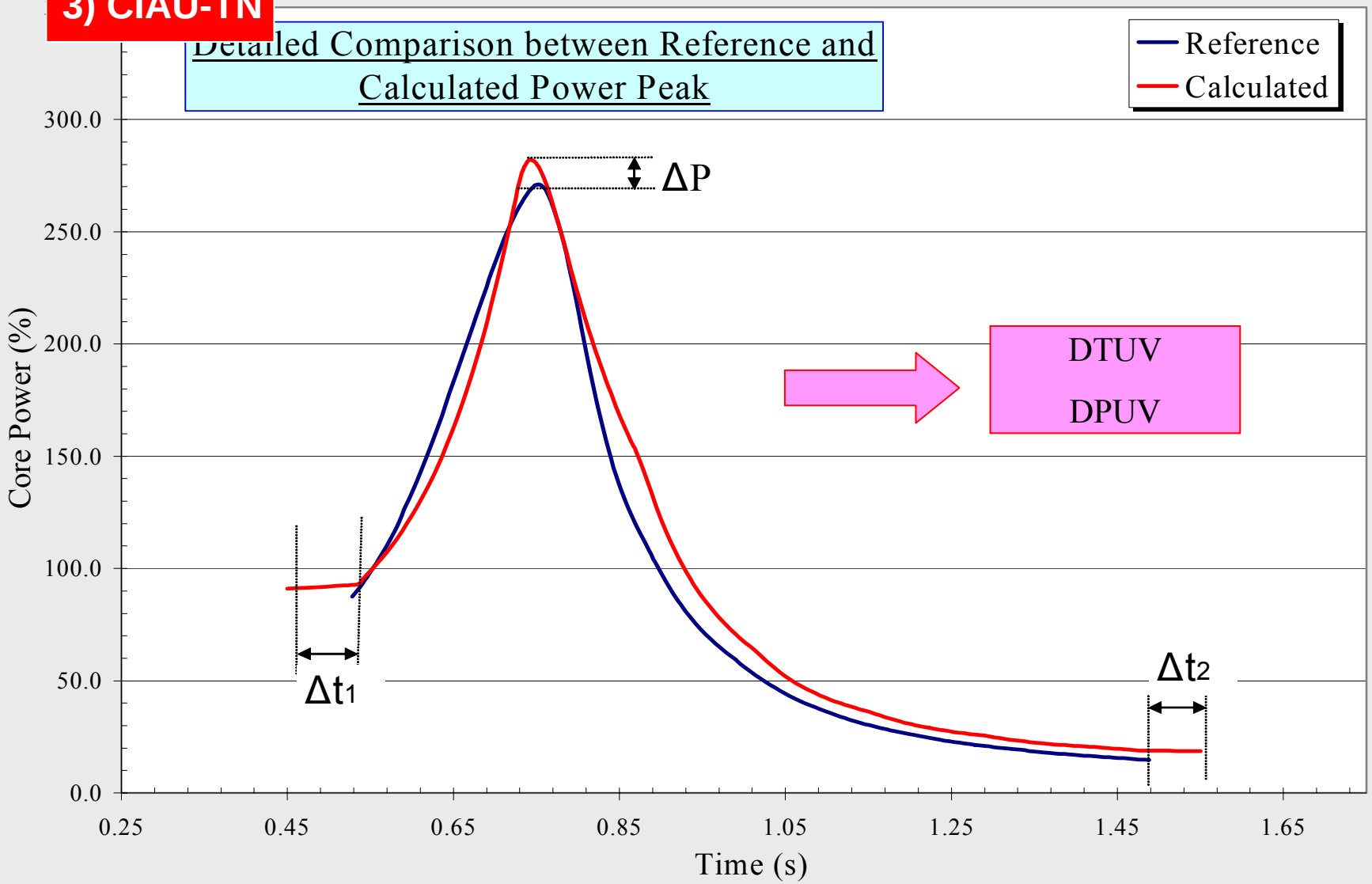
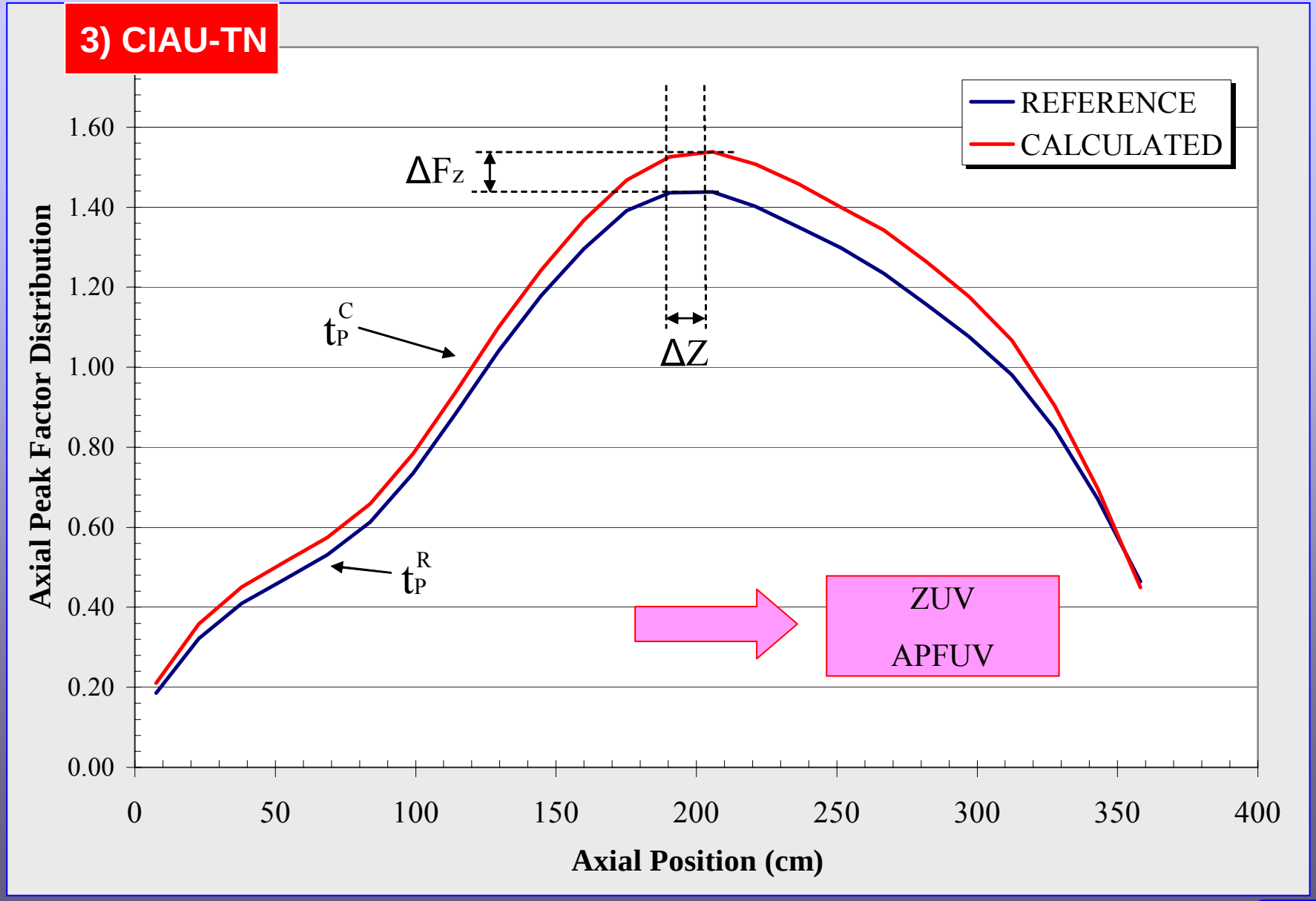


# The Extension to 3D NK-TH Analysis

**3) CIAU-TN**

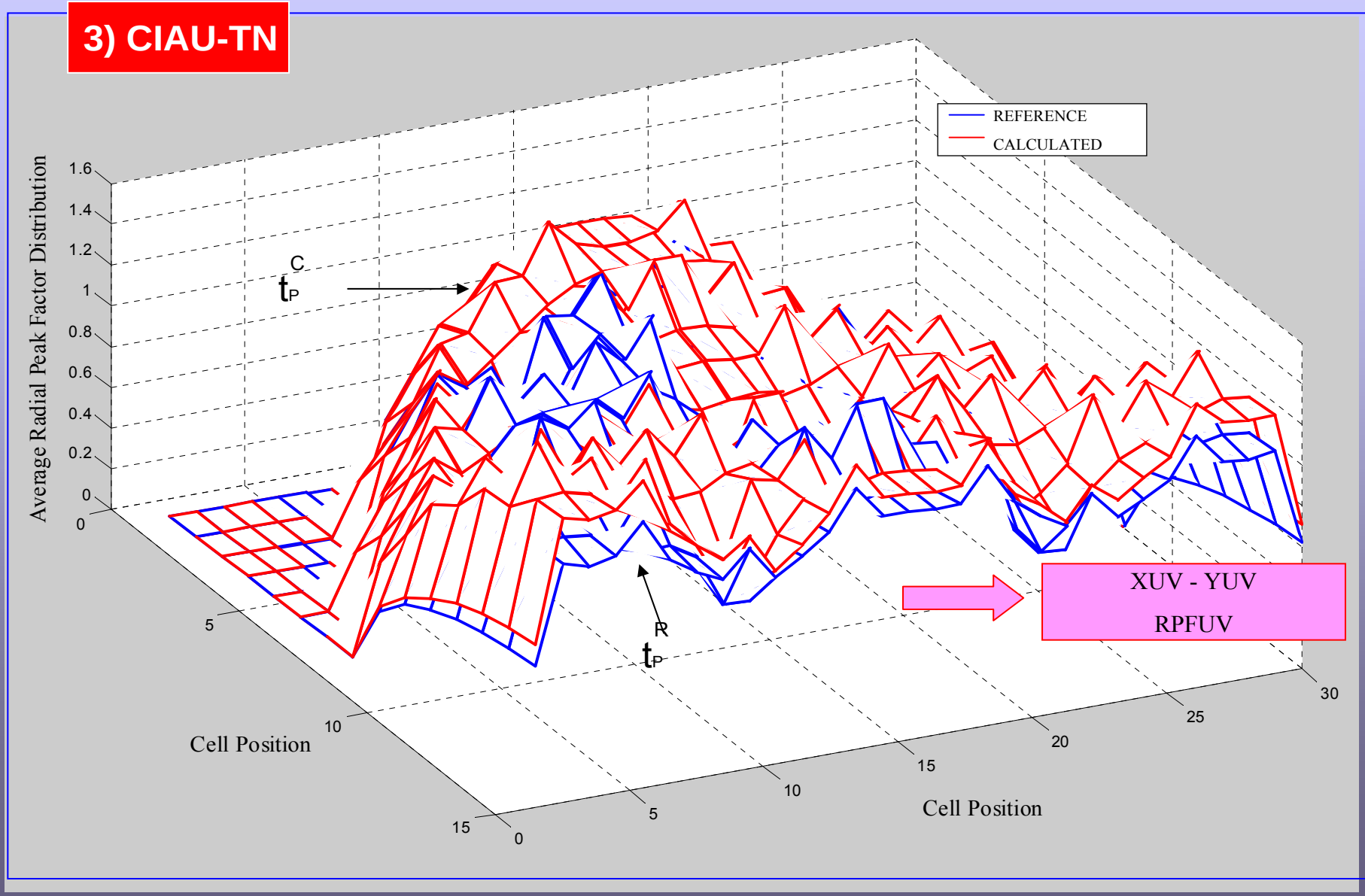


# The Extension to 3D NK-TH Analysis



# The Extension to 3D NK-TH Analysis

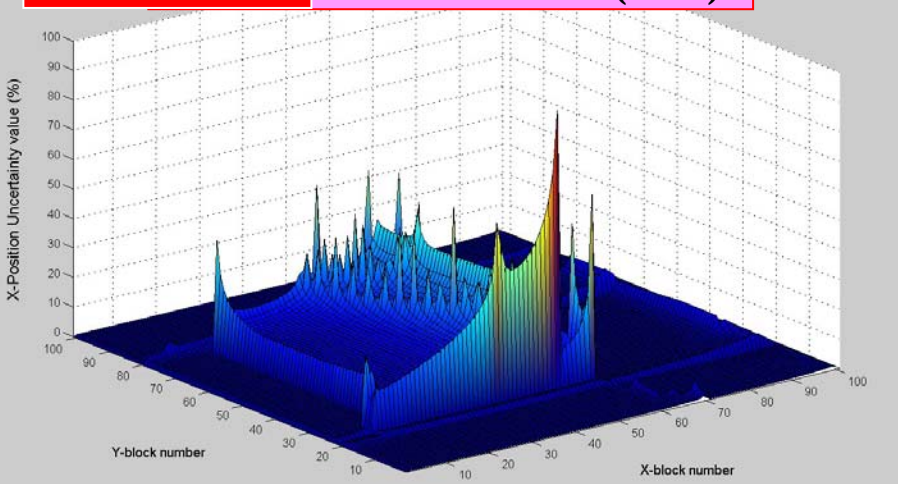
## 3) CIAU-TN



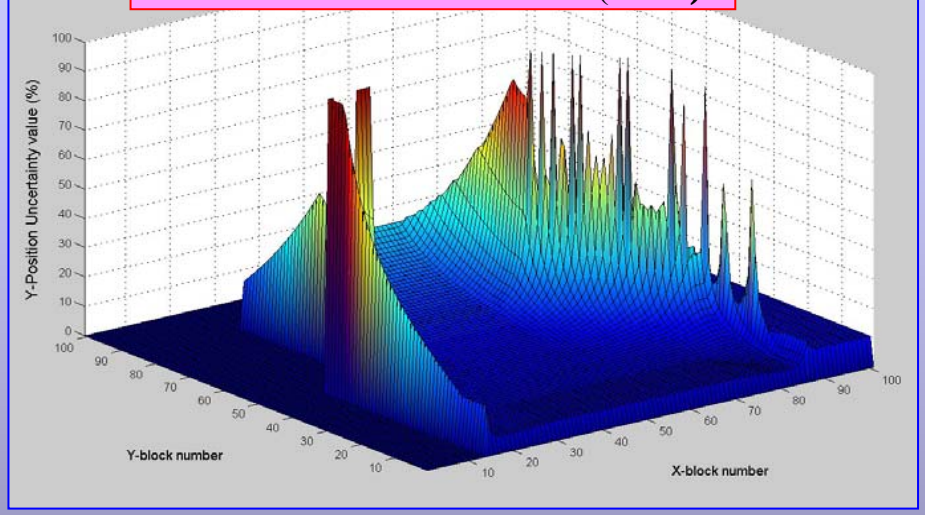
# The Extension to 3D NK-TH Analysis

**3) CIAU-TN**

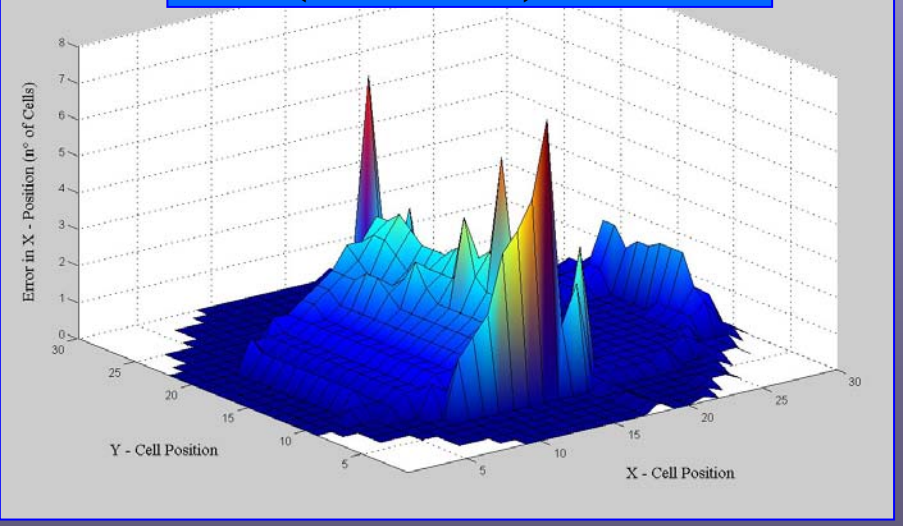
X – POSITION
TAINTY VECTOR **(XUV)**



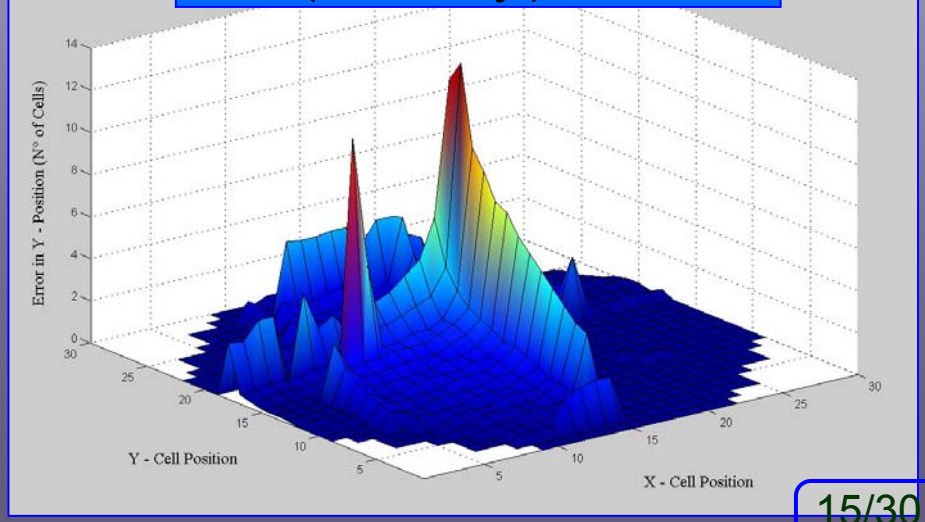

Y – POSITION
UNCERTAINTY VECTOR (**YUV**)




X - POSITION ERROR
**( XUV X x ) / 100**



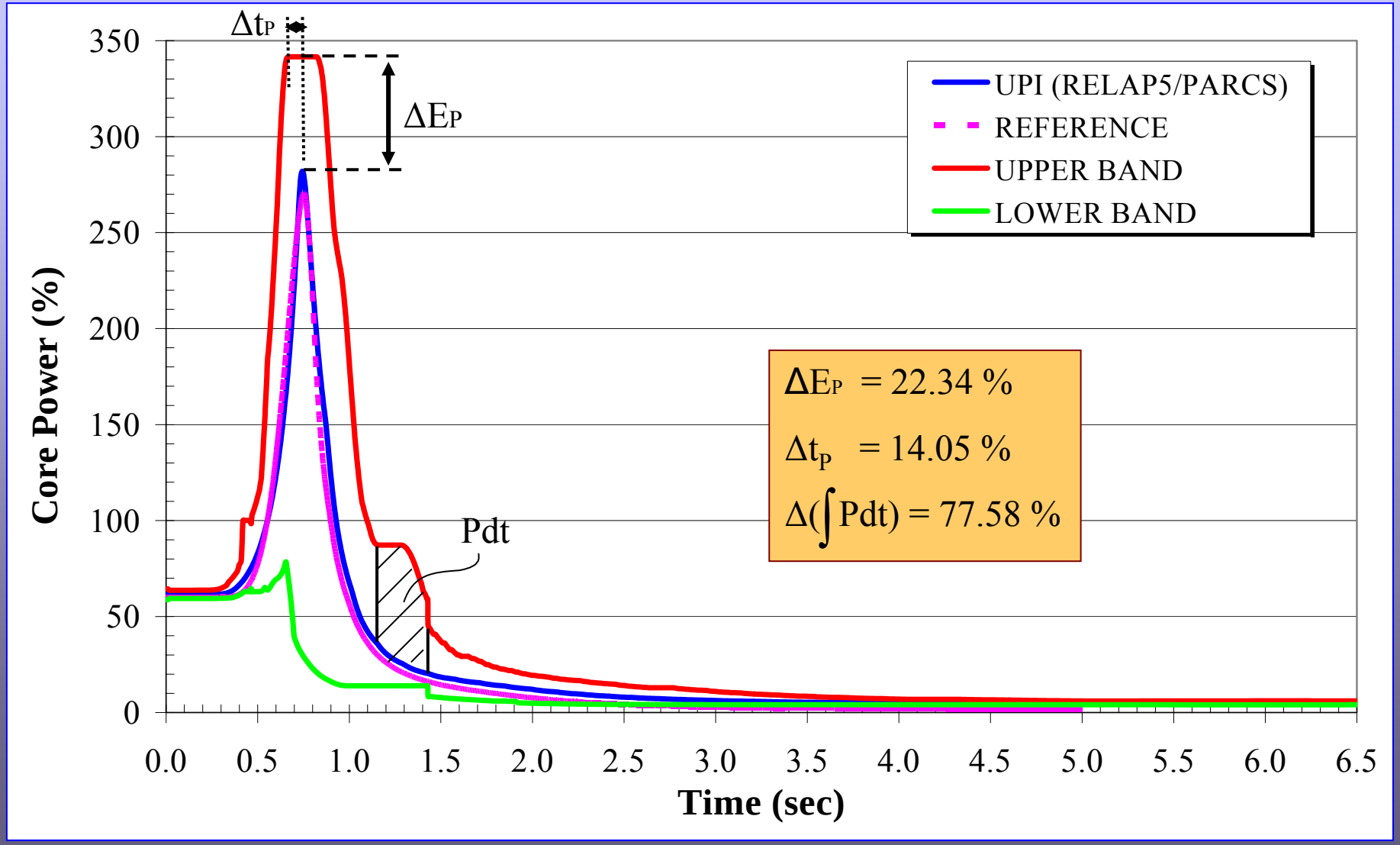

Y - POSITION ERROR
**( YUV X y ) / 100**



# The Extension to 3D NK-TH Analysis

3) CIAU-TN

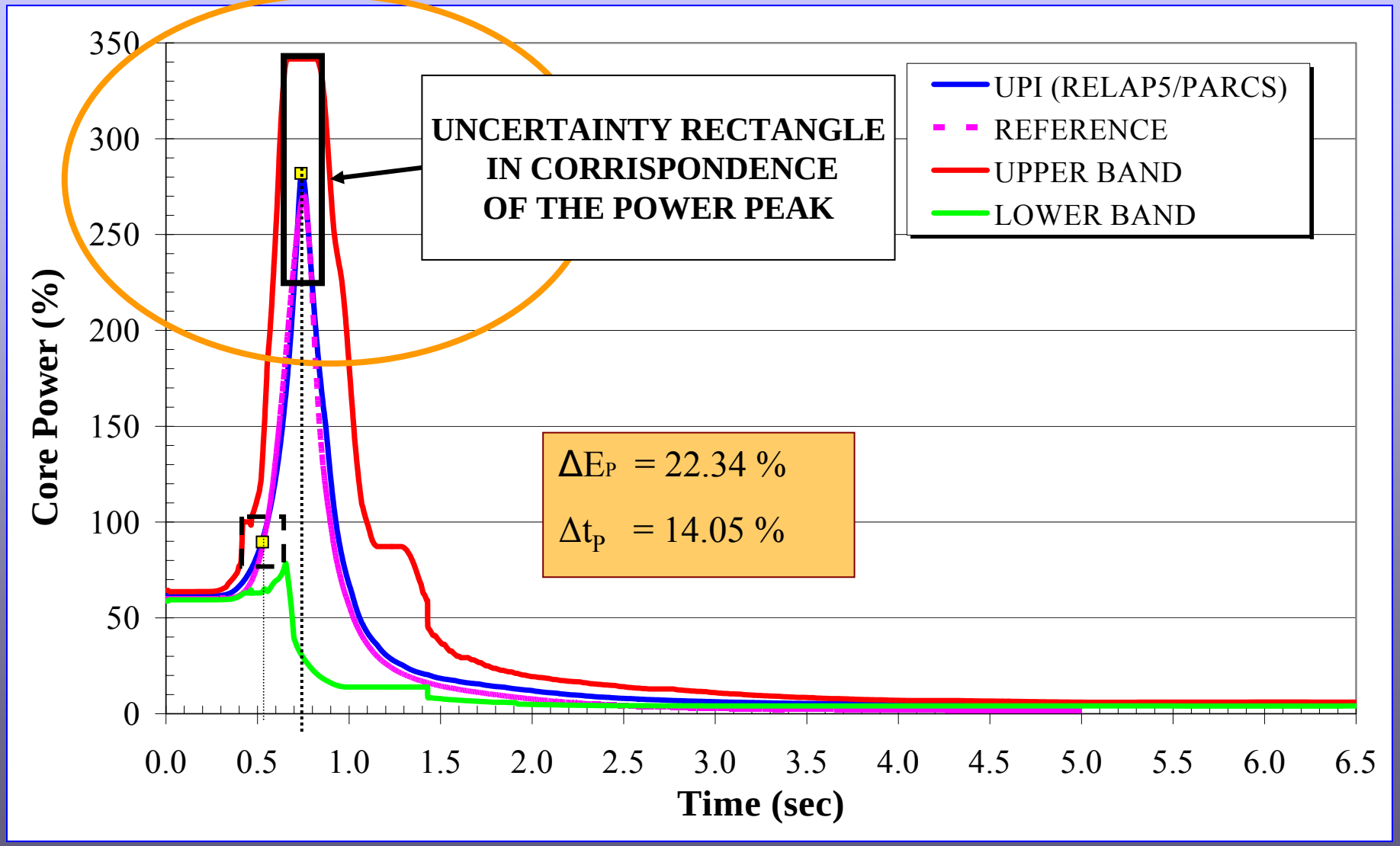
## TOTAL CORE POWER



# The Extension to 3D NK-TH Analysis

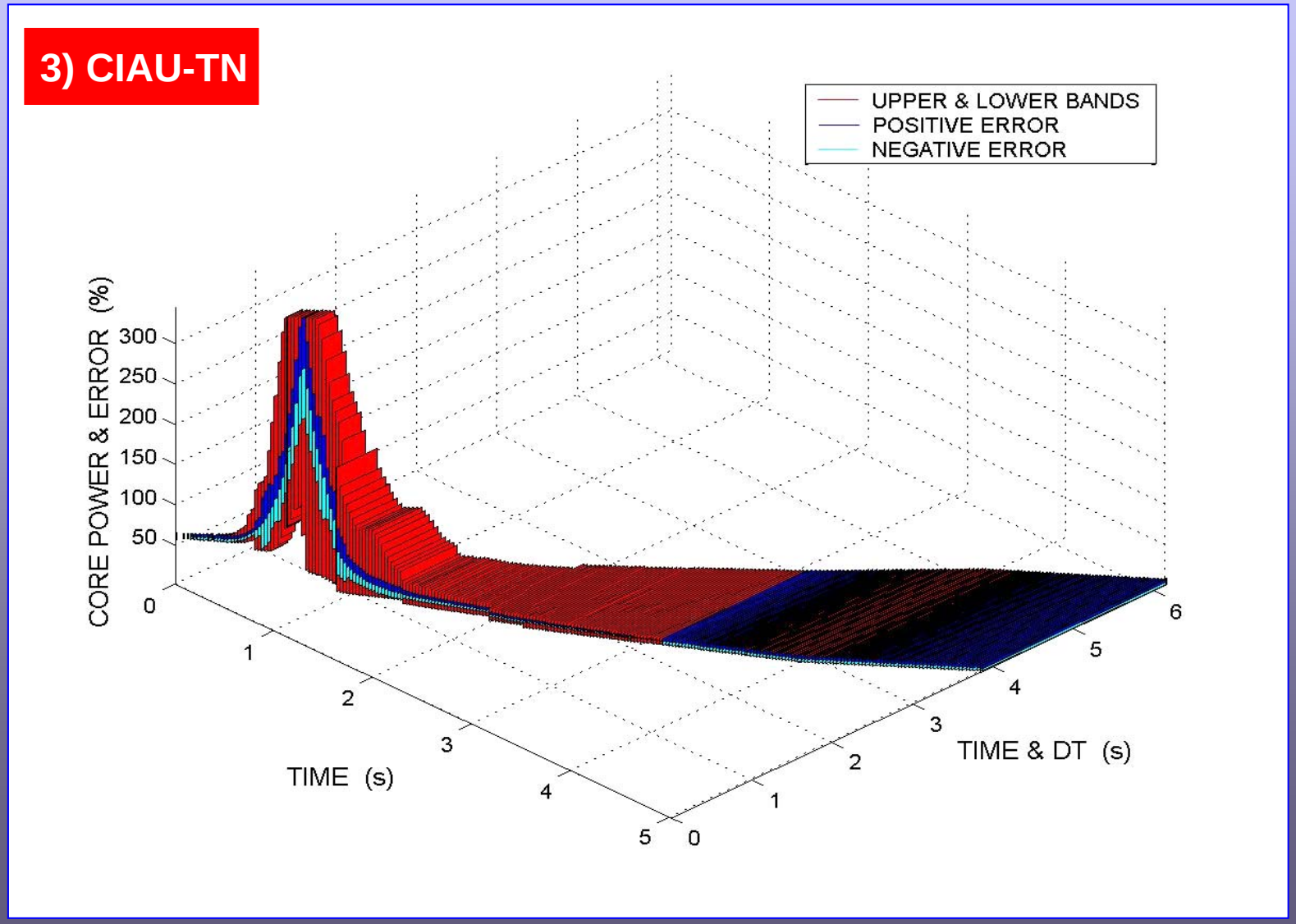
3) CIAU-TN

## TOTAL CORE POWER



# The Extension to 3D NK-TH Analysis

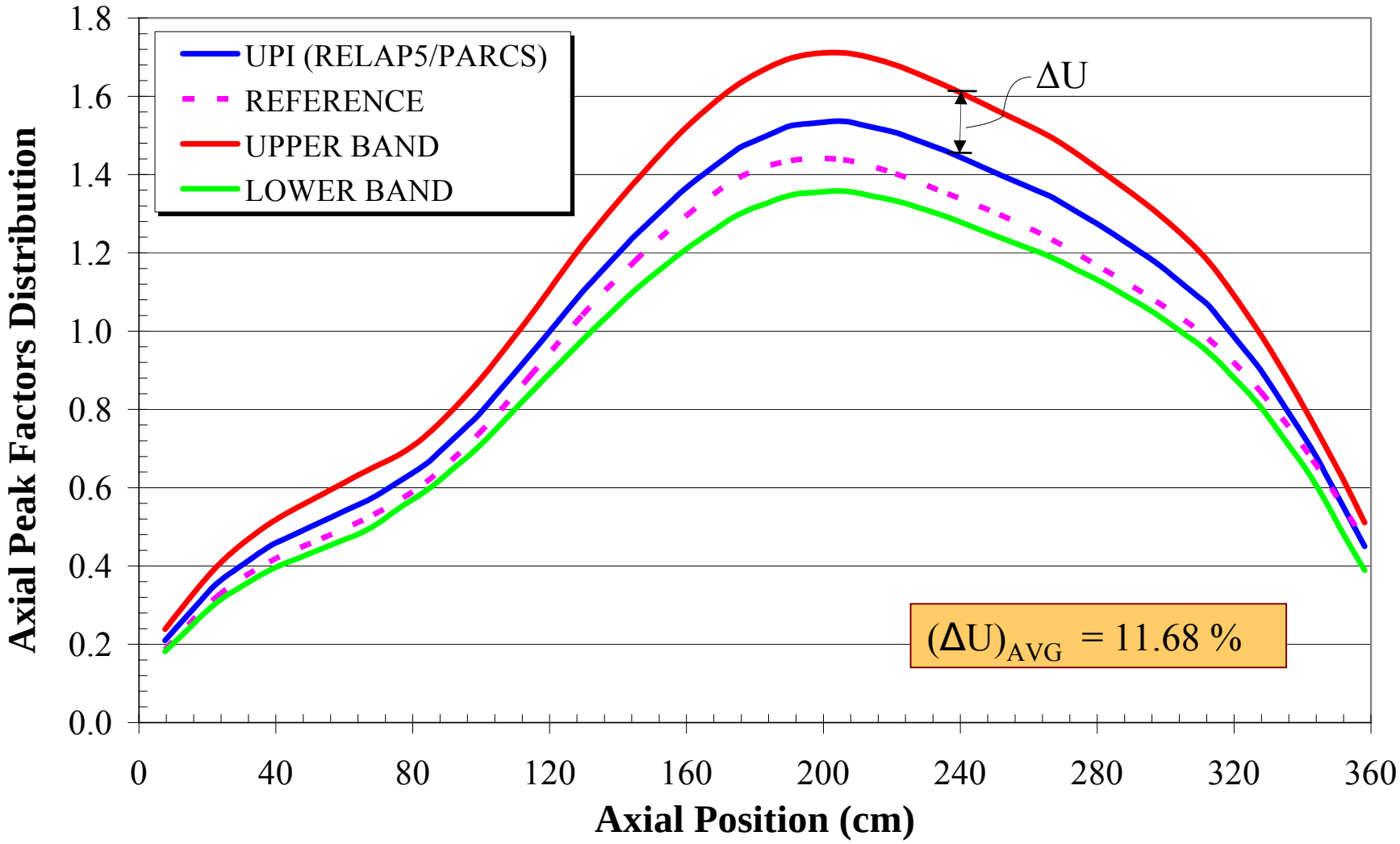
## TOTAL CORE POWER: 3D Representation of the Error



# The Extension to 3D NK-TH Analysis

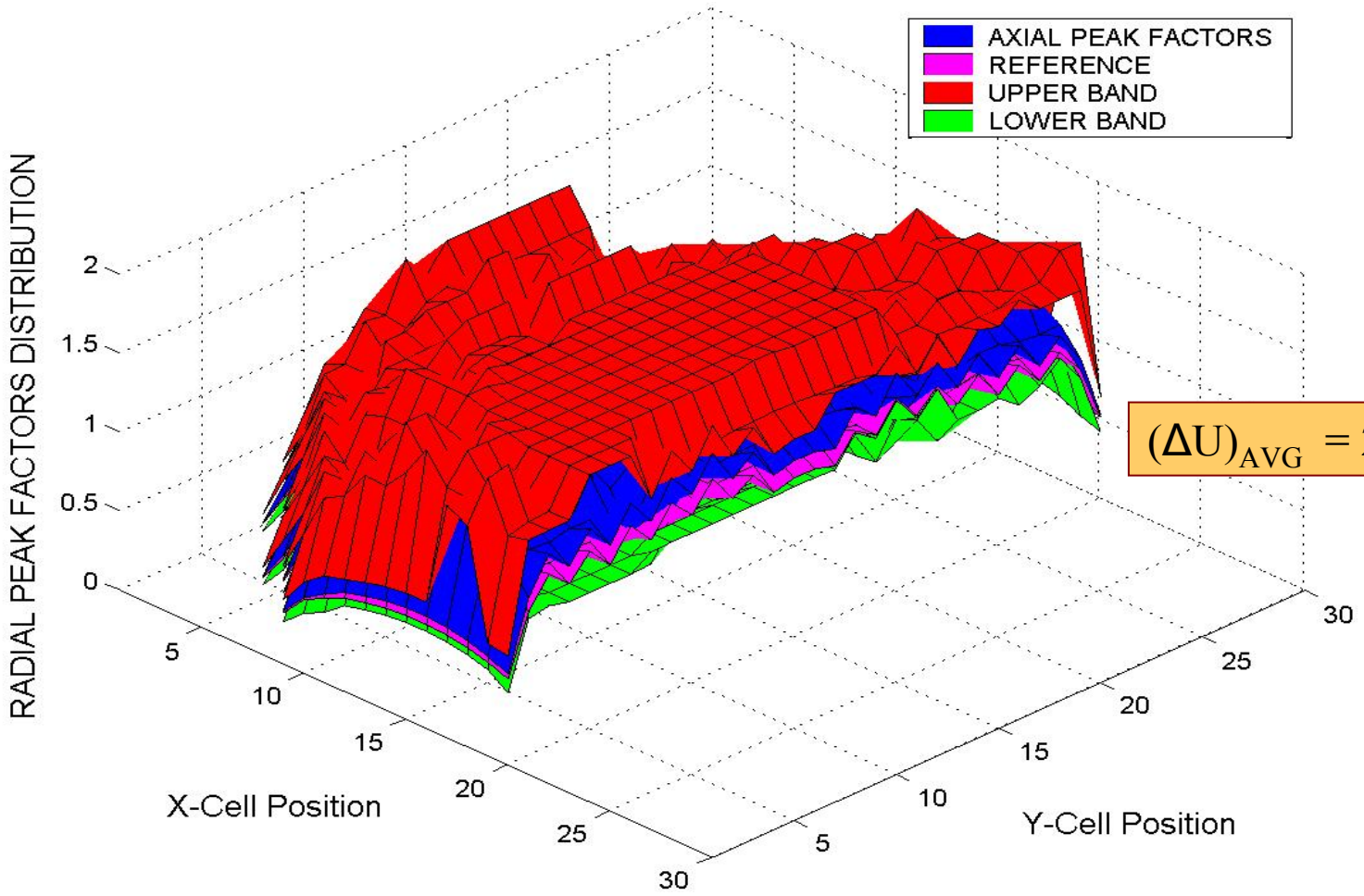
3) CIAU-TN

## AXIAL PEAK FACTORS DISTRIBUTION



# The Extension to 3D NK-TH Analysis

## 3) CIAU-TN RADIAL PEAK FACTORS DISTRIBUTION

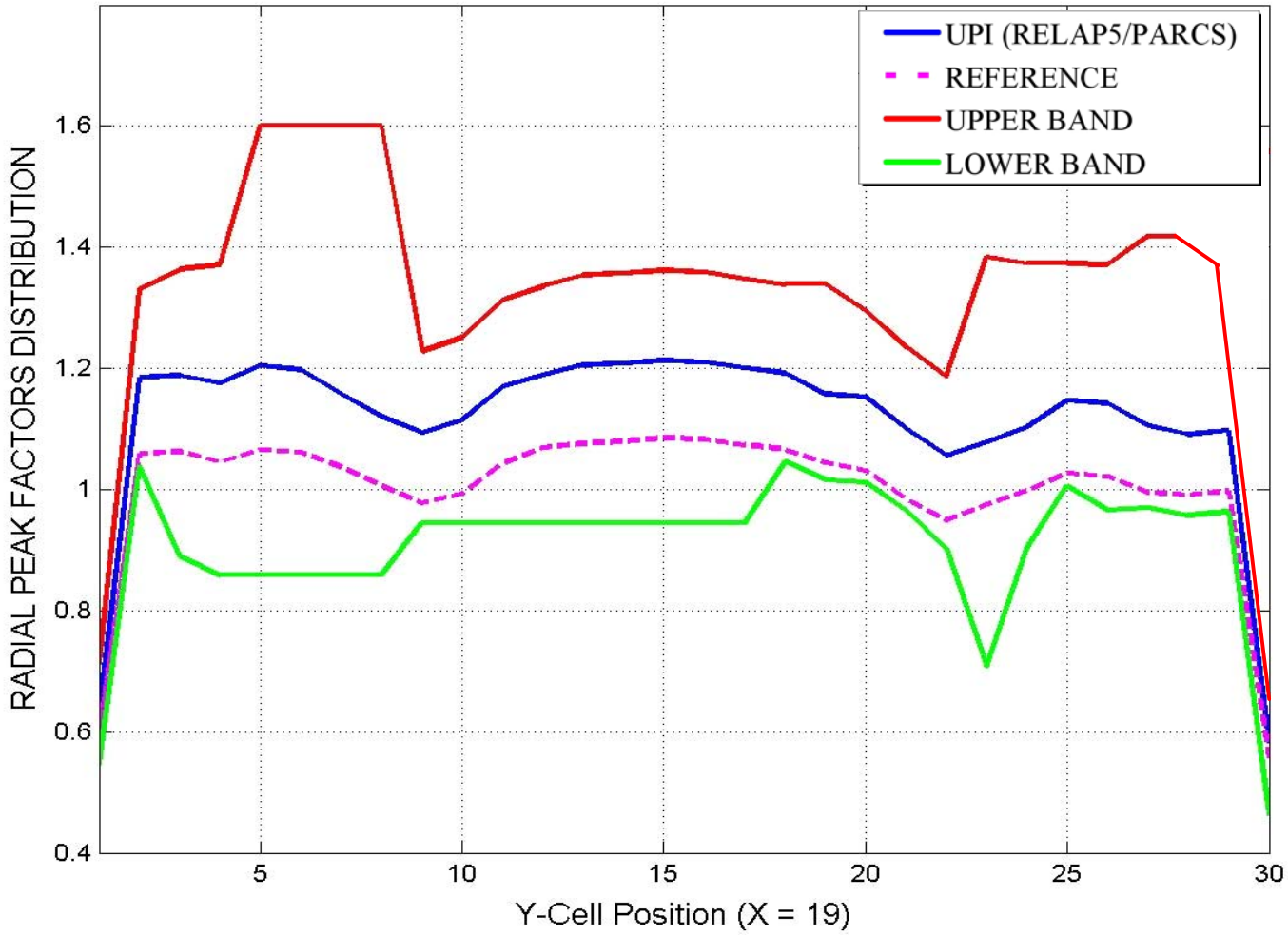



$(\Delta U)_{AVG} = 25.35\ \%$

# The Extension to 3D NK-TH Analysis

3) CIAU-TN

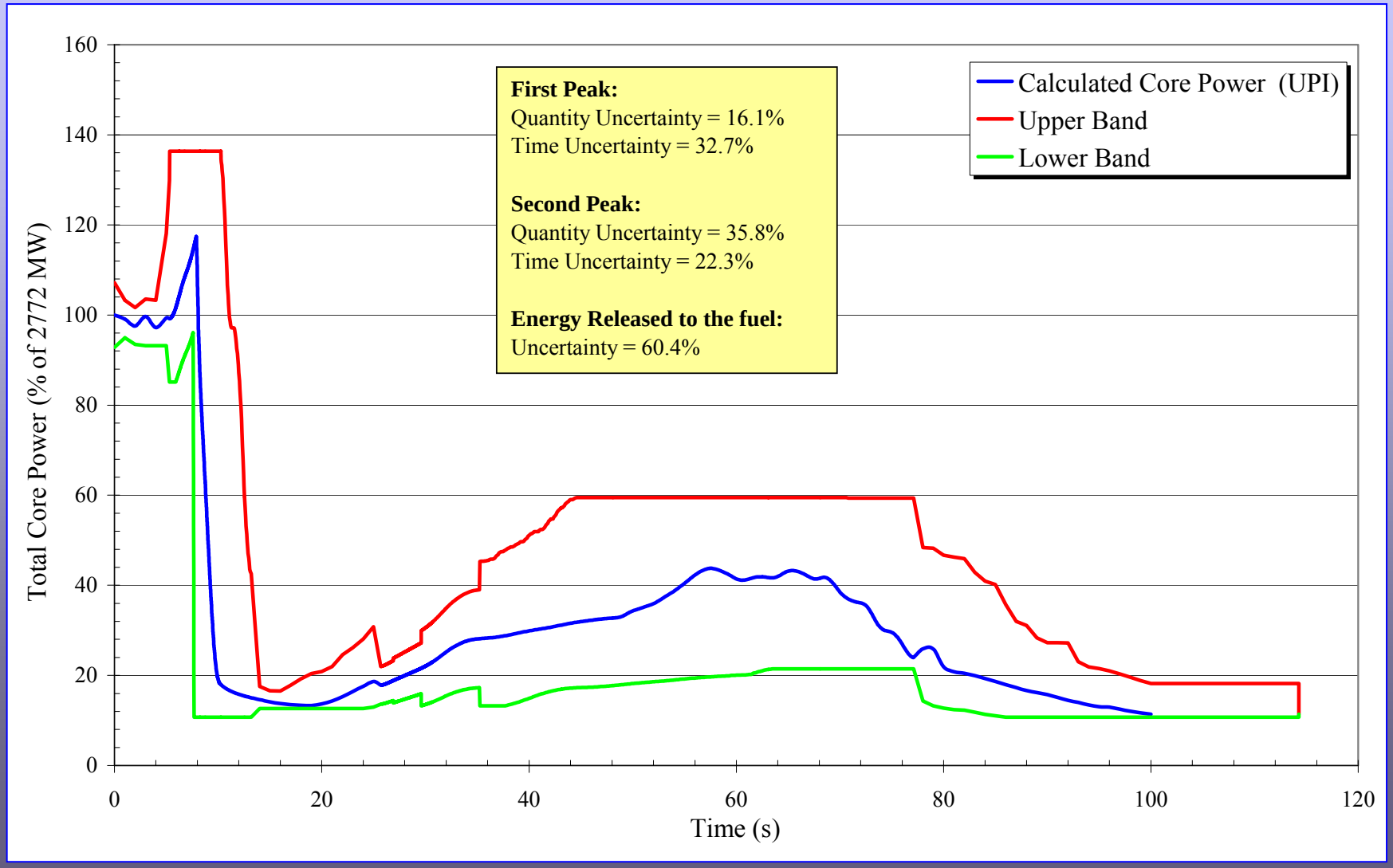
## RADIAL PEAK FACTORS DISTRIBUTION



# The Extension to 3D NK-TH Analysis

3) CIAU-TN

## TOTAL CORE POWER



# CONCLUSIONS 1 OF 2

- ✓ **UNCERTAINTY ORIGINS IN TH-SYS CALCULATIONS**
  ***"USER EFFECT" AND "CV+J" APPROACH ARE IMPORTANT SOURCES OF UNCERTAINTY.***

- ✓ **APPROACHES TO QUANTIFY UNCERTAINTY**
  ***PROPAGATION OF CODE INPUT UNCERTAINTY & PROPAGATION OF CODE OUTPUT ERROR HAVE BEEN DISTINGUISHED***

- ✓ **TOPICS TO BE CONSIDERED FOR UNCERTAINTY METHOD DEVELOPMENT & APPLICATION (TRUE).**

- ✓ **CIAU METHODOLOGY OUTLINED.**
  - ***THE IDEA***
  - ***THE ENGINE***
  - ***THE RESULTS FROM APPLICATION2***

# CONCLUSIONS 2 OF 2

- ✓ UNCERTAINTY METHODS ARE MATURE FOR INDUSTRIAL APPLICATION IN THE AREA OF SYS-TH AND DBA
- ✓ KEY DEVELOPMENTS OUTLINED IN THE AREA OF COUPLED 3D NK-TH APPLICATIONS: DEMONSTRATION OF MATURITY NOT ACHIEVED
- ✓ INTERNATIONAL ACTIVITIES IN PROGRESS:

A) OECD-CSNI BEMUSE PROJECT.

B) IAEA TECDOC TO BE ISSUED & TM BE+UNC (PISA SEPT. 2005).

C) EC NURESIM PROJECT – VALIDATION OF METHOD PROPOSED BY DAN CACUCI.