Joint ICTP-IAEA Essential Knowledge Workshop on
Deterministic Safety Assessment and
Engineering Aspects Important to Safety

Sensitivity and uncertainty

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Content of the lecture

- Definition sensitivity and uncertainty
- Sensitivity
  - Areas of the use
  - Limitations, examples
  - Identification of parameters
  - Application of the sensitivity analysis
- Uncertainty
  - BEPU approach
  - Identification of uncertainties
  - BEPU methods
- Regulatory review

Sensitivity and uncertainty

- ISP findings - different results with the qualified users with the same technical information
  - o Practical limitations
    - – Restrictions on time, financial and human resources
  - o Technical reasons
    - – Imperfect code models
    - – Unavailability of exact information
      - • User choice on various code models (e.g. heat transfer correlations)
      - • BIC: variations in steady-state value (e.g. primary pressure), unavailable (heat losses, discharge coefficient)

- Sensitivity and/or uncertainty analysis to evaluate the impact of these shortcomings

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Definitions (IAEA SSG-2)

- Sensitivity Analysis
  - Systematic variation of the code input variables and modeling parameters to determine their influence on the results of the calculations
- Uncertainty Analysis
  - Statistical combination of the influence of the plant conditions, code models and associated phenomena on the results

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Process of sensitivity and uncertainty

Sensitivity Analysis		Uncertainty Analysis
PIRT, Engineering judgement	Identification of the important parameters	PIRT, Engineering judgement
Single values – e.g. min., max., nom.	Definition of the marginal values	Comprehensive definition – e.g. interval, distribution function
Variation of single parameter/value – single run for each variation	Analysis	Statistic techniques to combine variation of parameters

Use of sensitivity analysis

- Before analysis
  - Optimization of the analysis (nodalization development, selection of the correlations)
  - Identification of conditions leading to the smallest margin to acceptance criteria (initial and boundary conditions)
- After analysis
  - Supplementation to the basic calculation to demonstrate the robustness of the results, no cliff edge effect
- Other applications
  - Support to uncertainty analysis – e.g. ranking of uncertain parameters

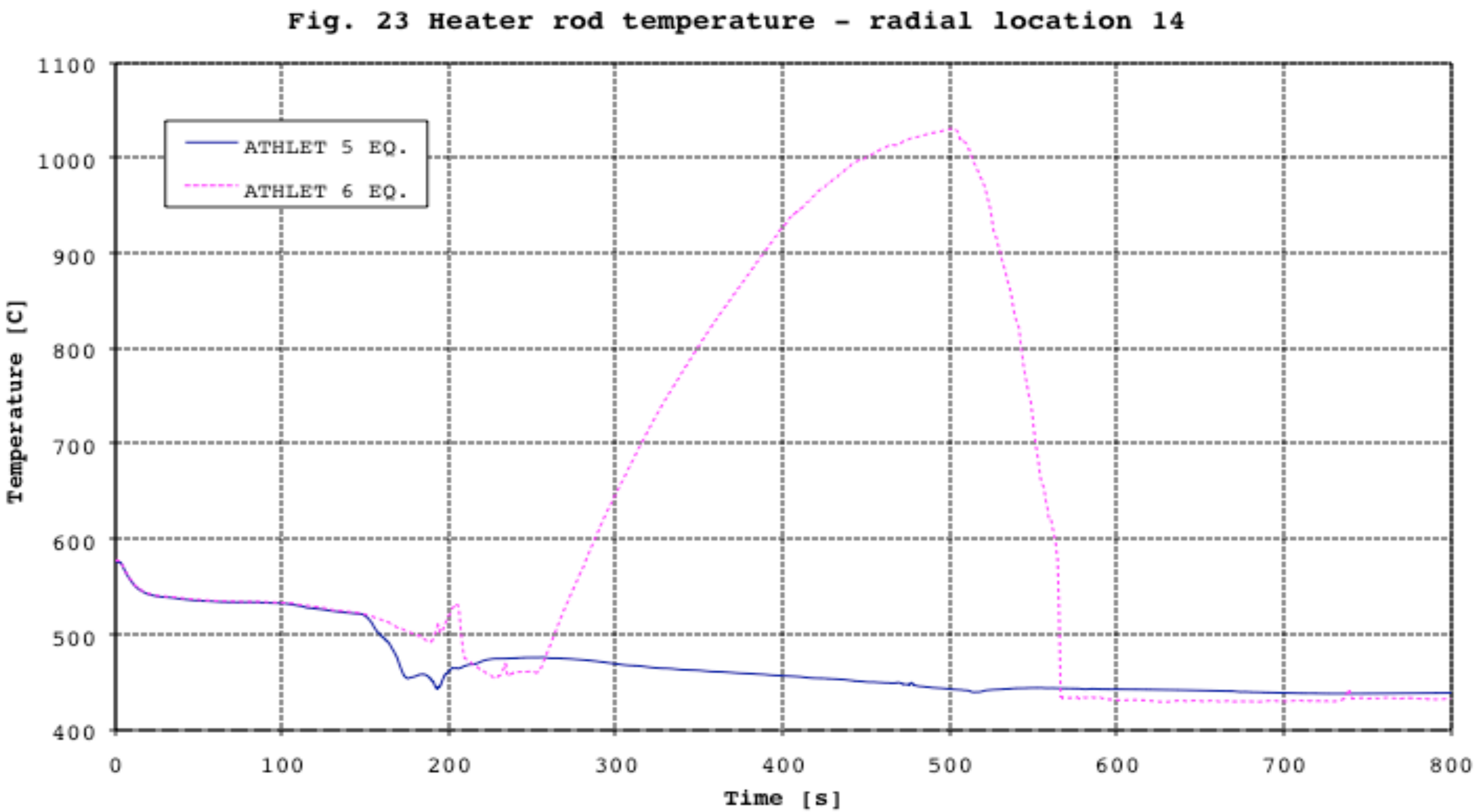
Limitations of sensitivity analysis

- Time consuming due to single variation of parameters and their values
  - Example:

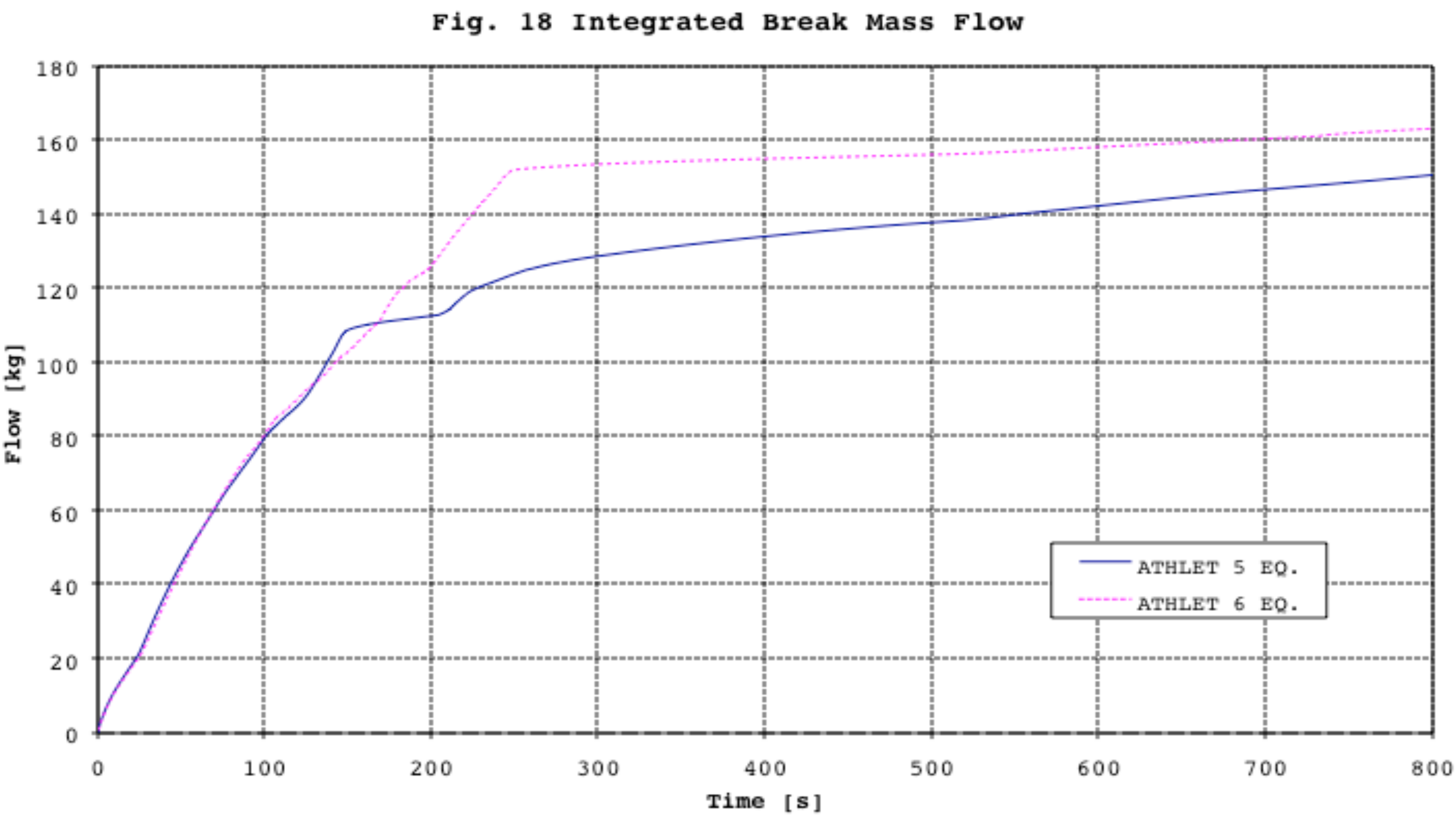
    Sensitivity evaluation: 5 parameters, minimum, maximum and nominal value taken into account

    => 15 runs – e.g. each run ½ day => 7.5 days of computing
- Most conservative case (and cliff edge effect) can remain hidden due to limited number of variation of values – see next slides

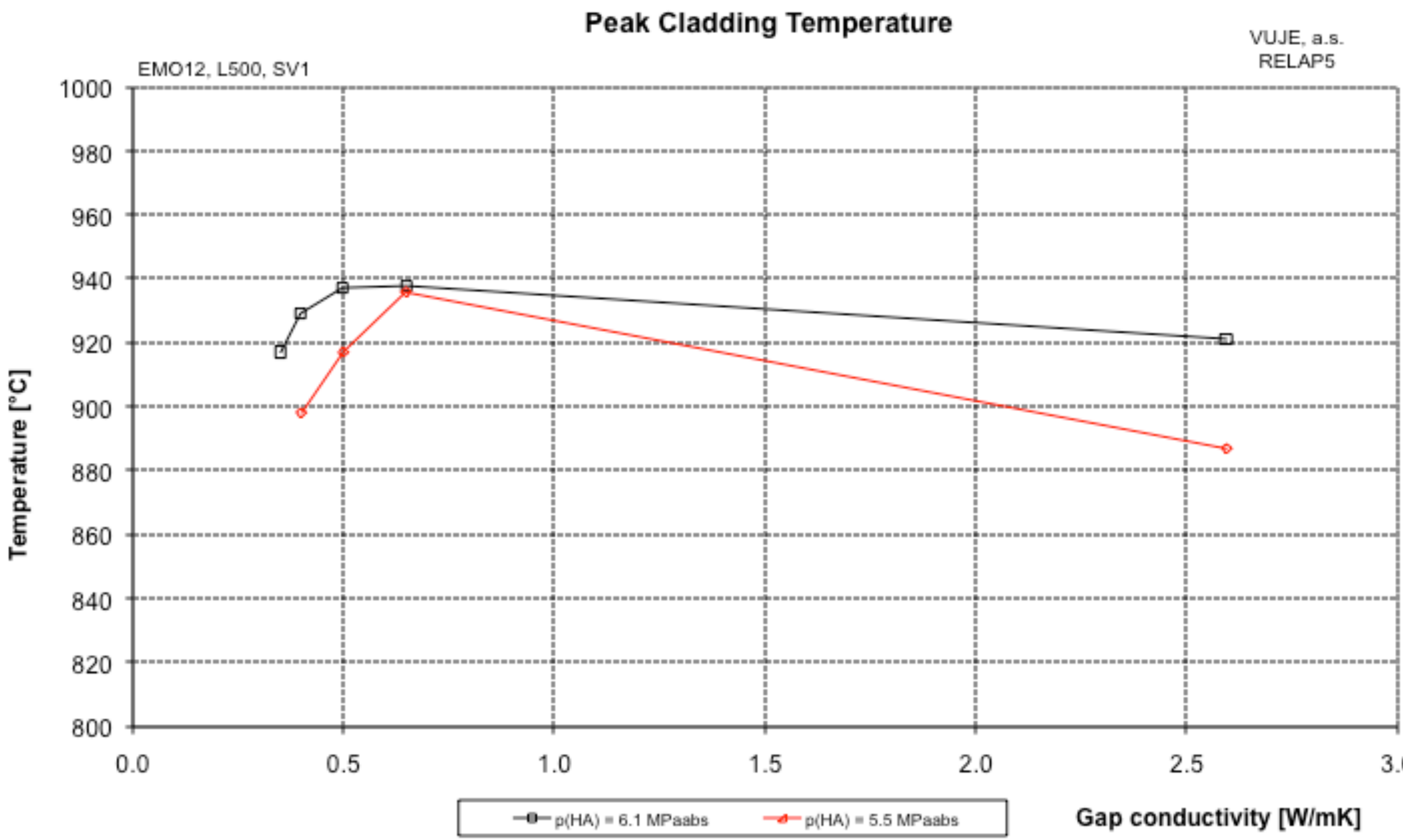
Sensitivity analysis – Cliff edge (PRZ surge line break analysis)



Sensitivity analysis – Cliff edge (PRZ surge line break analysis)



Sensitivity analysis – finding most penalizing value



Identification of parameters for sensitivity analysis

- Engineering judgement and accumulation of the knowledge and experience
- PIRT (Phenomena Identification and Ranking Table)
- Sensitivity measures from uncertainty analysis

Typical areas for sensitivity analysis

- **Initial and boundary conditions**
  - o Neutron-kinetic data
  - o Levels
  - o Flows
  - o Temperature
- **Systems and components**
  - o Valve opening times
  - o Pump start-up time
- **Code models choices**

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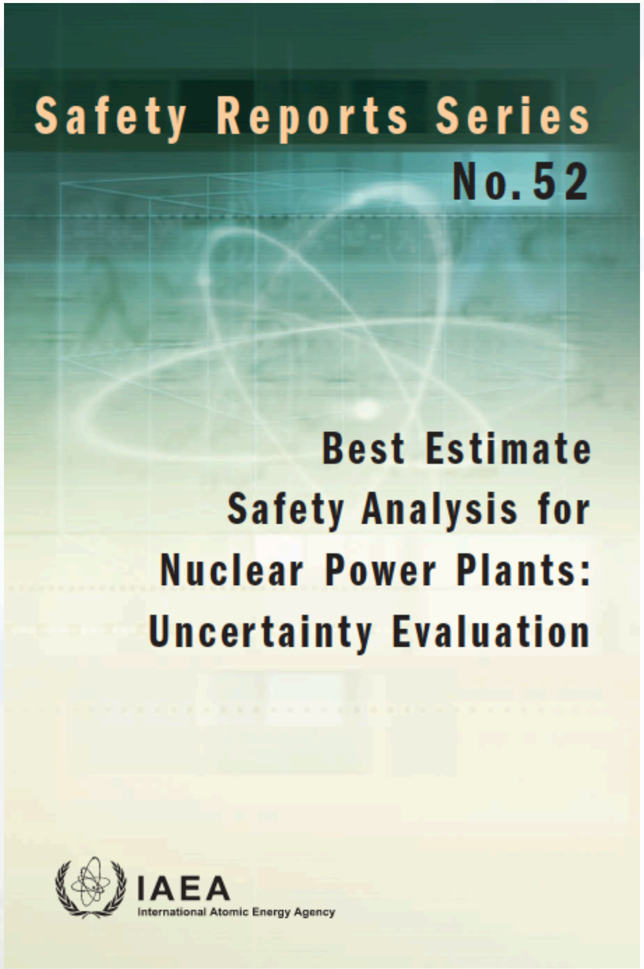
BEPU approach

- BE code available
- Sufficient information on uncertainties associated with safety analysis
- Methods how to treat uncertainties and calculate uncertainty bands



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BEPU approach

- Best Estimate (BE) code is one which:
  - Models the important phenomena realistically and can simulate the behavior of the plant system
  - Is free of deliberate pessimism regarding selected acceptance criteria
  - Contains a sufficiently detailed model to describe the relevant processes that need to be modeled
- BE analysis is one which:
  - Is free of deliberate pessimism in the inputs, calculation model, chosen acceptance criteria, etc.
  - Uses a best estimate code
  - Includes an uncertainty analysis

Principal steps in BE analysis

- Selection of the facility and definition of the PIE,
- Definition of the acceptance criteria,
- Selection of the appropriate computer code(s),
- Model development and preparation of the realistic analysis,
- Selection of the uncertainty method,
- Identification of the uncertain parameters and their uncertainty ranges,
- Preparation of the uncertainty analysis,
- Evaluation of the results in regard to the relevant acceptance criteria

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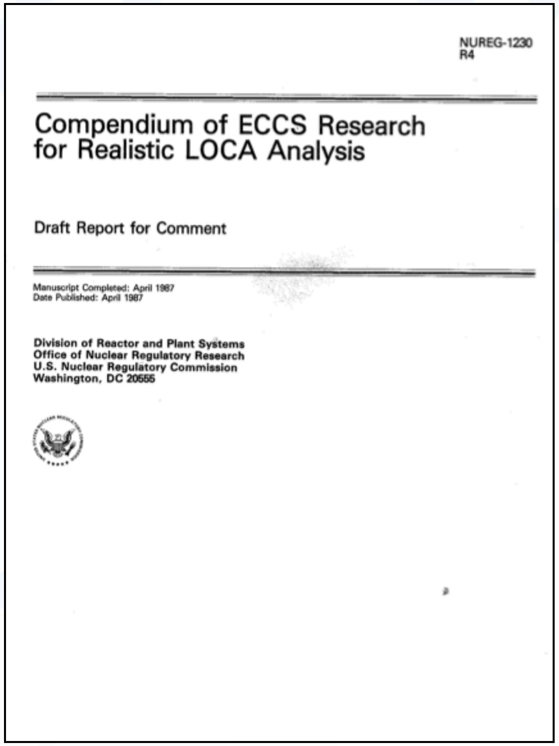
BEPU - uncertainties

- Code uncertainties
  - Balance equations
  - Closure and constitutive equations
  - Material properties
  - Special process and component models
  - Numerics
- Representation (nodalization) uncertainties
- Plant uncertainties
- User effect

CSAU - Overview

- 1974-1988: Extensive research to support the development of realistic and physically based analysis methods: Compendium of ECCS Research for Realistic LOCA Analysis, NUREG-1230, August 1988
- 1988: US NRC approved a revised rule for the acceptance of ECCSs: USNRC, "Emergency Core Cooling Systems, Revisions to Acceptance Criteria", Federal Register 53, 180, September 16, 1988
- 1989: the NRC provided guidance for the use of best-estimate codes: USNRC Regulatory Guide 1.157, "Best-Estimate Calculations of Emergency Core Cooling System Performance", May 1989
- Code Scaling, Applicability, and Uncertainty (CSAU) uncertainty evaluation methodology to support the revised ECCS rule and illustrate its application
- The CSAU was demonstrated first for LBLOCA (NUREG/CR-5249, 1989) and then for SBLOCA (NUREG/CR-5818, 1992)


NUREG-1230
R4

Compendium of ECCS Research
for Realistic LOCA Analysis

Draft Report for Comment

Manuscript Completed: April 1987
Date Published: April 1987

Division of Reactor and Plant Systems
Office of Nuclear Regulatory Research
U.S. Nuclear Regulatory Commission
Washington, DC 20555

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CSAU - Diagram

Element 1

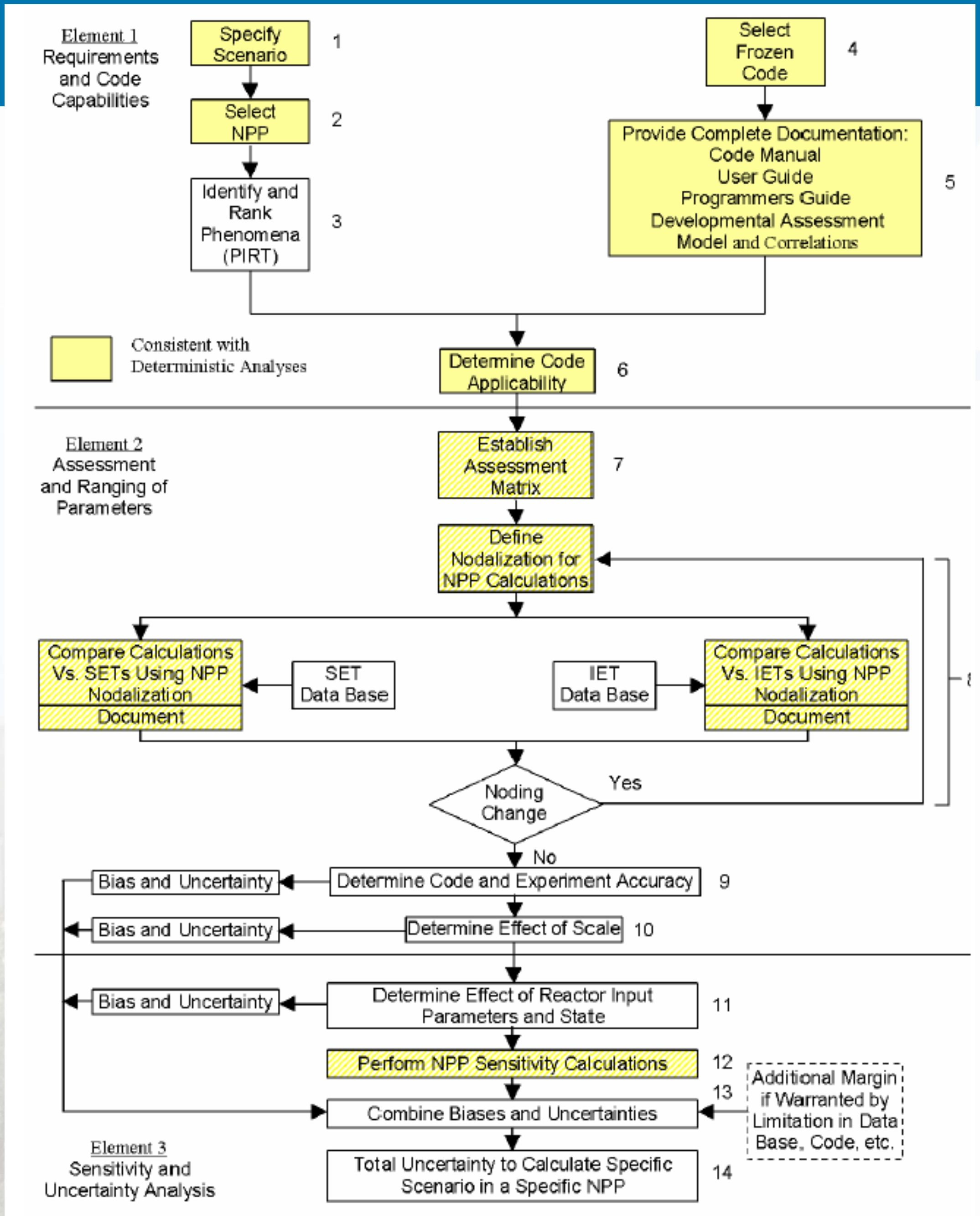
Requirements and code capabilities

Element 2

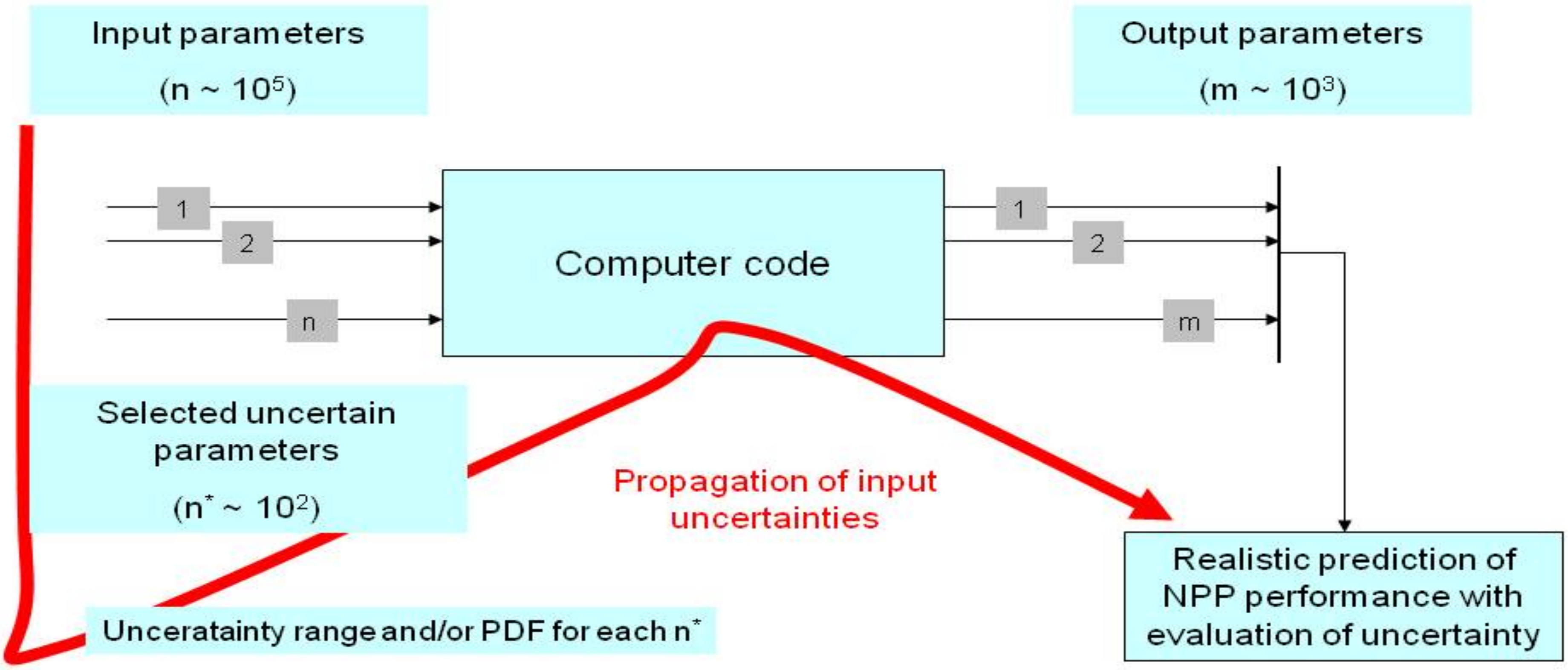
Assessment and ranging of parameters

Element 3

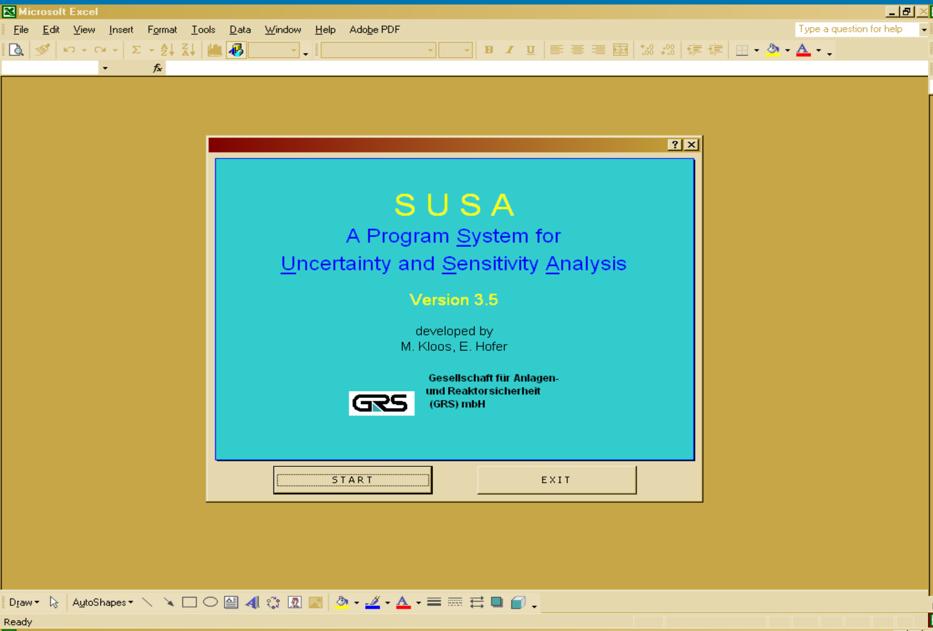
Sensitivity and uncertainty analysis

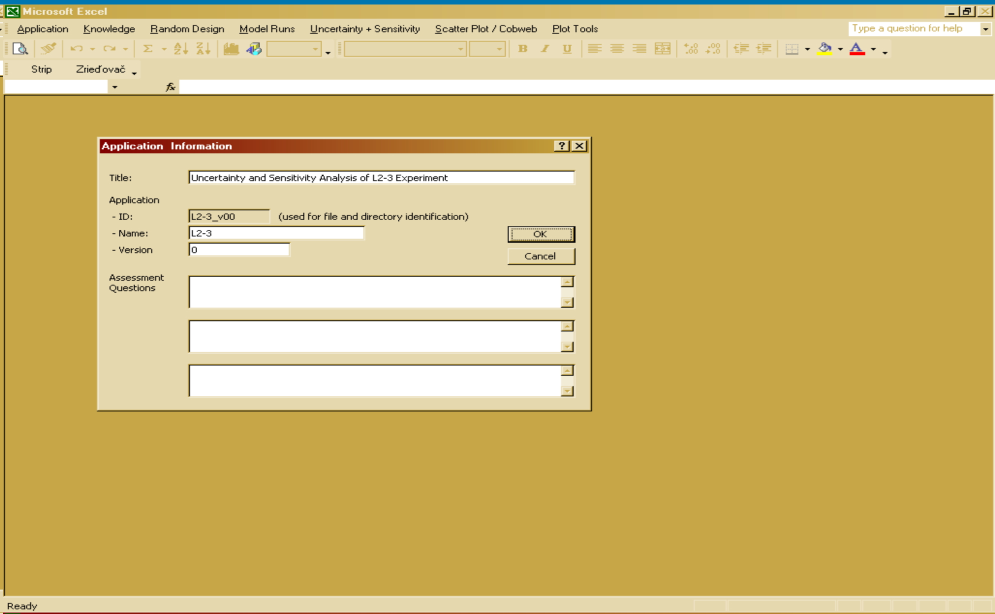


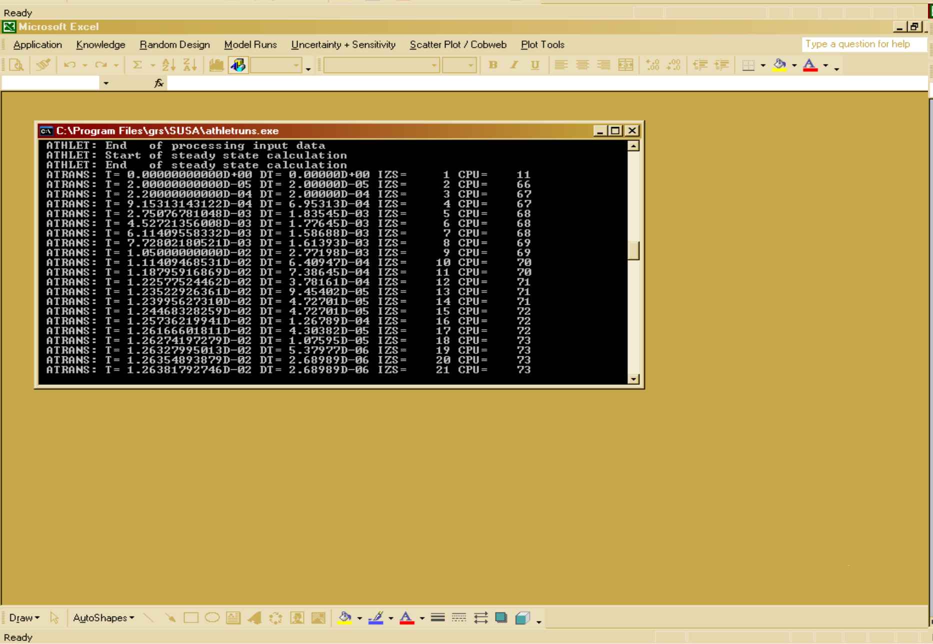
Current uncertainty principles

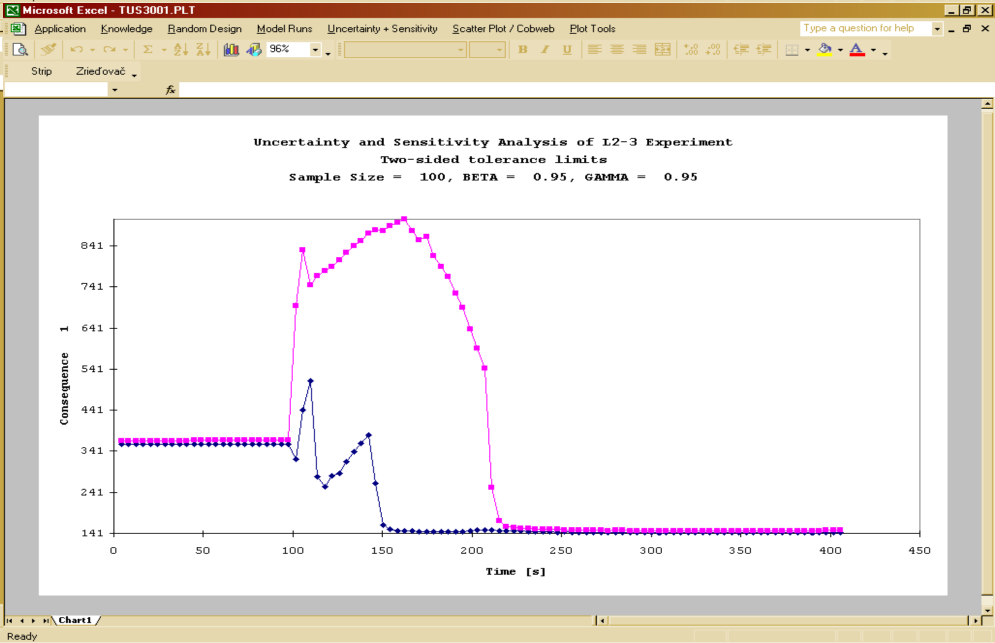


GRS method – uncertainty and sensitivity measures









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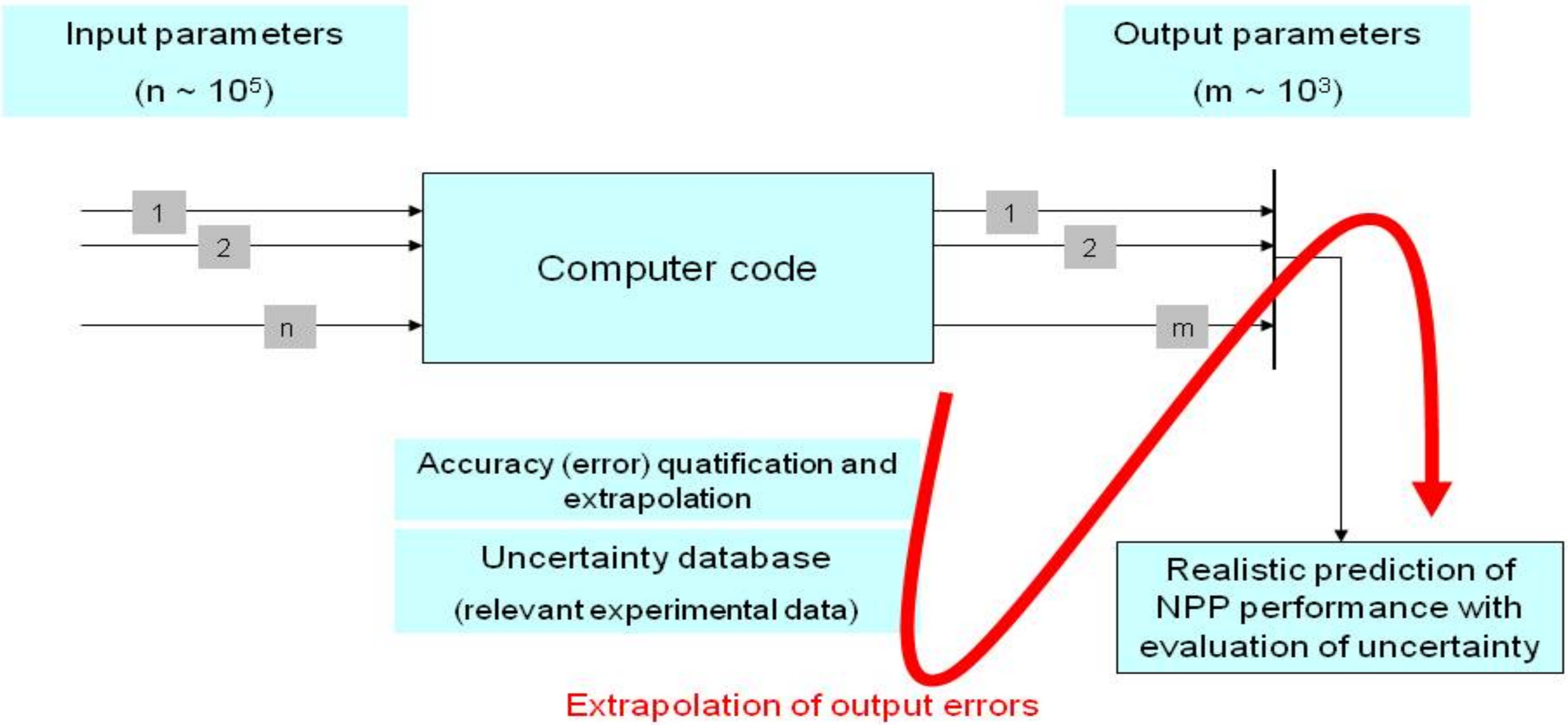

UMAE and CIAU method

- Uncertainty method based on Accuracy Extrapolation (UMAE)
- Code with Internal Assessment of Uncertainty (CIAU)
- Extrapolation of accuracy comparing the calculated results with relevant experiments
- Accuracy $$a(t) = \frac{Y_E(t)}{Y_C(t)}$$
- Fourier transformation – accuracy amplitude

$$A(f) = \int_{-\infty}^{\infty} a(t) e^{-i2\pi f t} dt$$

- Averaging over large number of data from various experiments of different plant types, events, scales etc.

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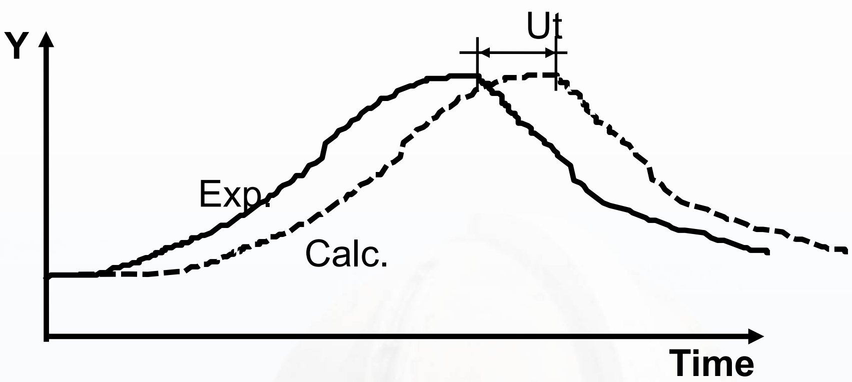
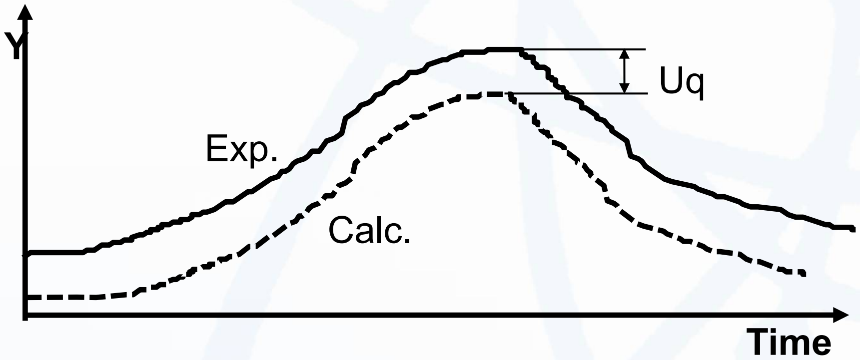
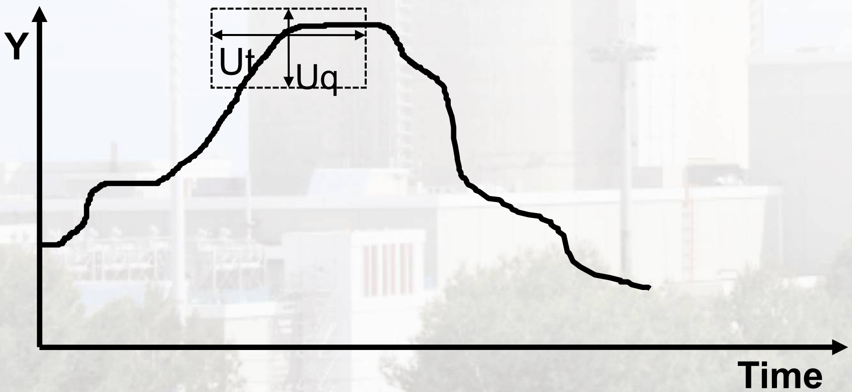
UMAE and CIAU method



a) only Time Error is present



b) only Quantity Error is present



c) Combination of Errors

d) Derivation of Continuous Uncertainty Bands

BEPU analysis – LOFT L2-3

- LOFT
  - o Integral test facility
  - o 2-loop model of Westinghouse PWR
  - o Scaling ratio 1:50
  - o Power 50 MWe (real fuel)
- L2-3
  - o Double-ended break on the cold leg
  - o 36 MWe initial power, linear power 39.4 kW/m
  - o 1 ECCS train (HP, LP, Accu)
  - o MCP running

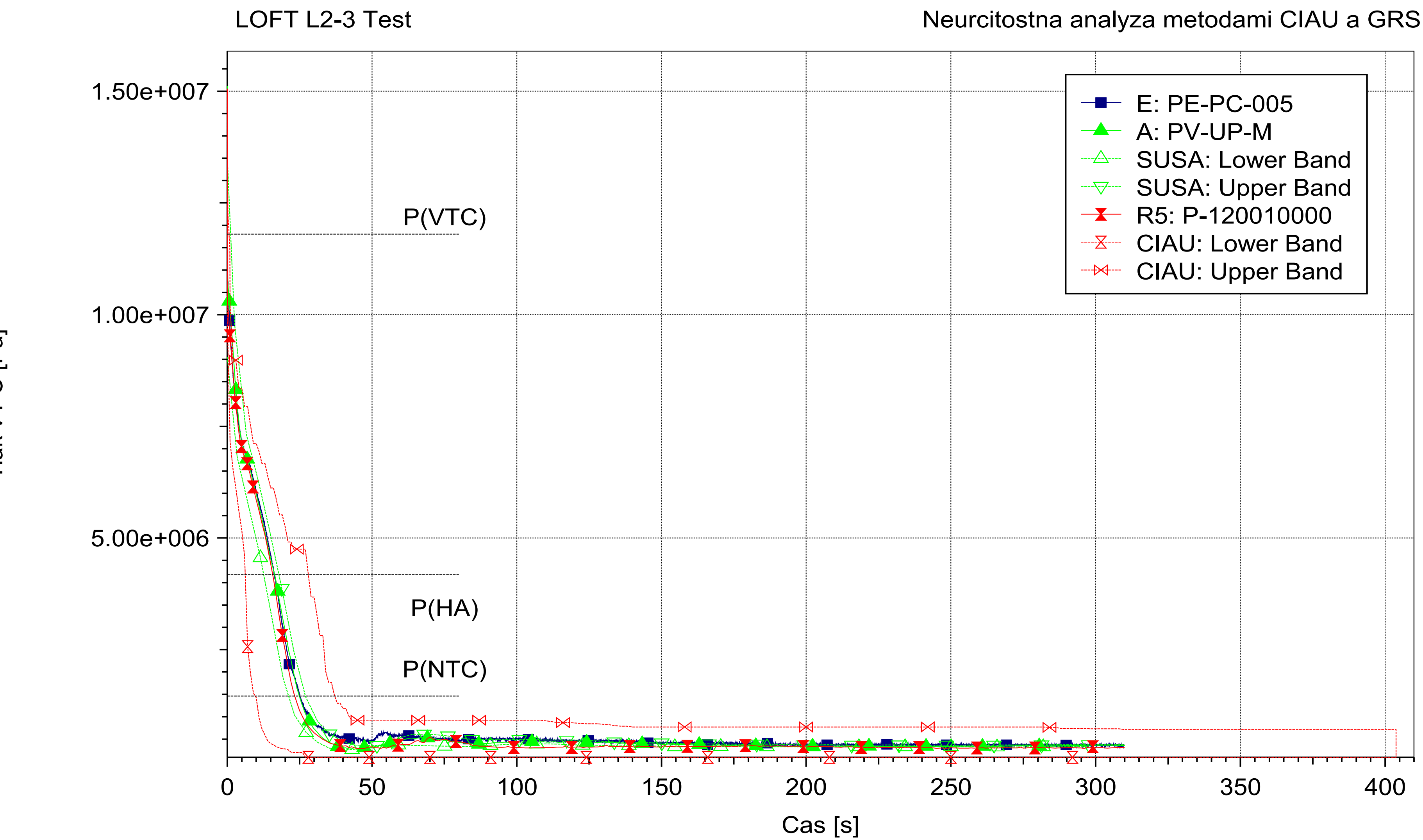
BEPU analysis – LOFT L2-3

- BEPU analysis
  - RELAP5 + CIAU method
  - ATHLET + GRS method
  - Comparison of two computer codes and two methods with experimental results

BEPU analysis – LOFT L2-3

- Procedure
  - Input model preparation
  - Input model qualification
  - Realistic simulation of the experiment and its qualification
  - Uncertainty analysis

BEPU analysis – LOFT L2-3



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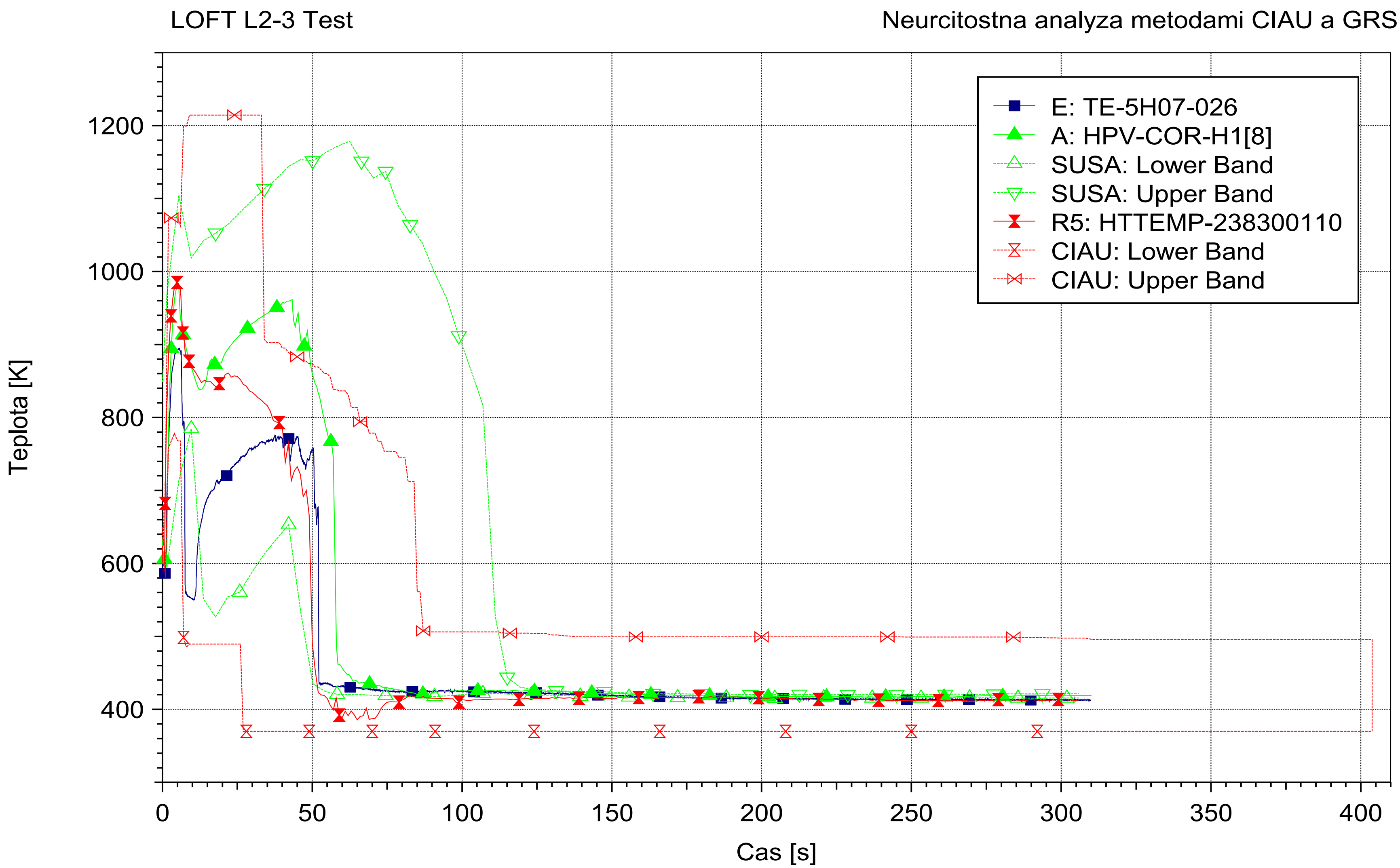
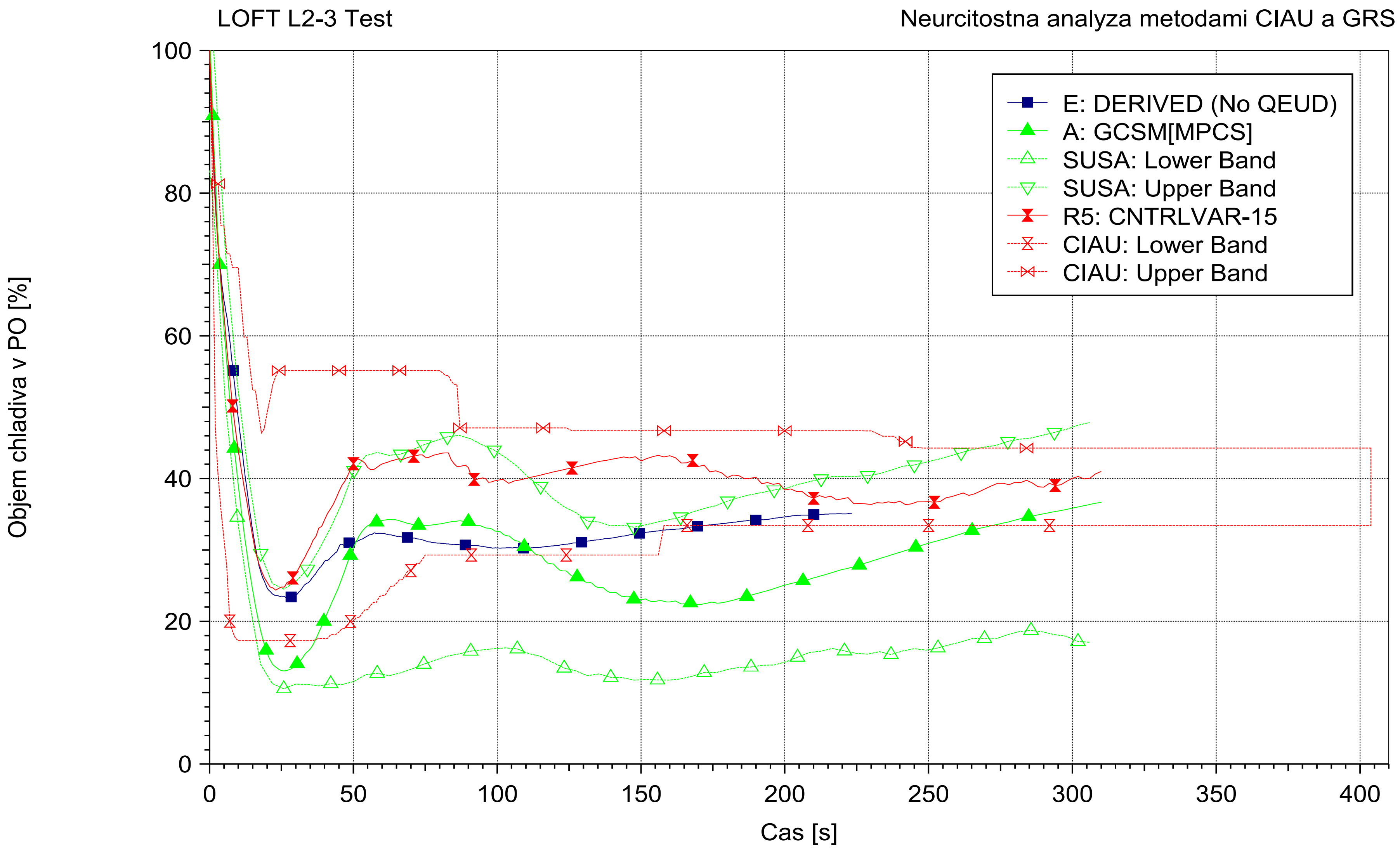


BEPU analysis – LOFT L2-3



BEPU analysis – LOFT L2-3

- Uncertainty bands bound the experimental results
- PCT
  - 914 K (in 6 second) – experimental value
  - 983 K (in 5 second) – best estimate value of RELAP5 simulation
  - 978 K (in 6 second) – best estimate value of ATHLET simulation
- Uncertainty bands
  - 1214 K (during the period of time from 7 to 33 seconds) – upper band given by CIAU uncertainty evaluation
  - 1102 K (first peak at 5 second) and 1178 K (second peak at 63 second) – upper band given by GRS uncertainty evaluation

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Regulatory review of the sensitivity analysis

- Challenging task
- There is no assurance that the analysis presented in safety documentation is the "right" one (e.g. most conservative, bounding etc.)
- Sufficient amount of sensitivity analysis should be presented (usually as supporting technical documentation) to demonstrate the robustness of the analysis, appropriate choice of BIC etc.
- Regulator should have the competence to evaluate this sufficiency and knowledge what to ask for
  - Practical experience with analysis
  - TSO support

Regulatory review of the uncertainty analysis

- Challenges associated with uncertainty analysis
  - New approach – few applications to serve as an example
  - Still developing – new methods, techniques
  - More complex, more sophisticated supporting procedures (FFTBM, PIRT, statistical tools for treatment of uncertainties …)
- Most important areas for review
  - Uncertainty method – areas of application, V&V, limitations
  - Identification, ranking of uncertainties, definition of the uncertainty ranges
  - QA program

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Acceptance of the uncertainty analysis

- Uncertainty method is recognized and accepted on international level which gives a certain guarantee of proper application
- Development of the uncertainty method is systematic which presumes new information, experience and progress in the area is periodically incorporated
- Sufficient and appropriate documentation is available for correct application of the uncertainty method by the user
- Careful verification is provided
- Uncertainty method is systematically validated within the range of the expected application

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