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UNCERTAINTY ANALYSIS IN MODELLING
UAM-2006 WORKSHOP

Summary Record

28-29 April 2006
Pisa, Italy

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English - Or. English

NUCLEAR SCIENCE COMMITTEE

Uncertainty Analysis in Modelling
UAM-2006 Workshop

Hotel Duomo, Pisa, Italy
28-29 April 2006

Hosted by
the University of Pisa, Italy

SUMMARY RECORD

Background and Purpose of the Workshop

In recent years there has been an increasing demand from nuclear research, industry, safety and regulation for best estimate predictions to be provided with their confidence bounds. Consequently an "in-depth" discussion on “Uncertainty Analysis in Modelling” was organised at the June 2005 NSC meeting, with three presentations covering relevant topics. In addition, discussions were held at the Avignon M&C and the Washington ANS meetings, which led to a proposal for launching an Expert Group on "Uncertainty Analysis in Modelling". This group would be related - but distinct from - the ongoing expert group on "LWR Transients and Stability Benchmarks". At its December 2005 Bureau meeting, the OECD/NEA Nuclear Science Committee (NSC) endorsed holding a workshop with the aim of defining future actions and a programme of work. It was proposed that the group should have the following mandate:

1. To elaborate a state-of-the-art report on current status and needs of uncertainty analysis in modelling, including design and safety applications, with emphasis on multi-physics (coupled) and multi-scale simulations.
2. To identify the opportunities for international co-operation in this area that would benefit from coordination by the NEA/NSC
3. To draw a roadmap for the development and validation of the methods and codes required for uncertainty analysis in design and safety applications, including the benchmarks adequate to meet those ends, the schedule and organization of its realization

Scope and Technical Content of the Workshop

The main scope covers uncertainty (and sensitivity) analysis (SA/UA) in best estimate modelling for design and operation of nuclear reactor systems, including methods that can be used for safety evaluations. The following topics are proposed for the workshop:

1) The current uncertainty (and sensitivity) analysis methods
   a) Main characteristics of the methods and implementations
   b) Range of applicability and examples of applications
   c) Issues and limitations of current methods

2) Needs for improvement in current and/or for new advanced SA/UA methods
   a) Identify the improvements in current SA/UA methods and the R&D efforts needed
   b) Identify the new advanced methods for SA/UA and the R&D efforts needed
   c) Evaluate the previous alternatives and set priorities.
3) Integration of methods deriving from previous R&D efforts within NSC and CSNI scopes, and proposals
   a) Level or stage of the required R&D efforts: scientific (NSC), qualification for safety applications (CSNI).
   b) Proposals of co-ordination and actions for the NSC and CSNI: scope and time-schedule.

Introduction

Francesco D'Auria welcomed participants on behalf of the University of Pisa, which was hosting the workshop and as a member of CSNI Working Groups. There are currently two programmes in this area: the BEMUSE project of CSNI, and a CRP at the IAEA on Uncertainties, preparing a "state-of-the-art report". The present workshop is complementary to these activities, which provided input for its preparation.

José Aragonés, General Chair of the Workshop and representing the NSC, provided the background. The issue of uncertainty analysis had been discussed during the last several years within the NSC. At the last NSC meeting (June 2005) an in-depth discussion was held on the holding of a workshop to discuss the current status and needs of uncertainty analysis in modelling, including design and safety applications, with emphasis on multi-physics (coupled) and multi-scale simulations, and to draw a roadmap for the development and validation of such methods and codes, including the benchmarks adequate to meet those ends, the schedule and organisation for its realisation.

Enrico Sartori welcomed participants on behalf of the OECD and mentioned that one of the objectives is to provide results of relevant parameters computed in complex simulations with reliable confidence bounds. Recently an enhanced co-operation and co-ordination of activities between the CSNI, and the NSC and the Data Bank was agreed on, including close co-ordination of activities in the uncertainty analysis area. Also an increased demand was made to provide basic nuclear data with their uncertainties and covariance matrices. Two sub-groups of the Working Party on (nuclear data) Evaluation Co-operation (WPEC) were consequently established to address these issues.

The agenda was approved with minor amendments (see Annex I).

Participants introduced themselves. There were in all 40 participants from 16 countries, representing 26 organisations or establishments. Participants represented research (50%), university(25%), regulatory bodies(15%) and industry(10%).

Presentations

In all eighteen presentations were made in 3 sessions. First the current uncertainty and sensitivity analysis methods were presented, followed by the needs for improvements in current and/or for new advanced SA/UA methods. The final session chaired by D.G. Cacuci included an experts' round-table on integration of methods deriving from previous R&D efforts within NSC and CSNI scopes, during which proposals were submitted for future co-ordinated work. The detailed programme is provided in Annex II and the presentations made were distributed to participants on CD-ROM.

Panel Discussion

D. G. Cacuci

Clearly, applications for UA need to be identified and studies need to be kept focussed. For applications, methods need to be integrated and the gaps identified and filled.

As a first step we need to define and agree on the terms used. There are different aspects for different "errors" and uncertainties; the terminology for sensitivities is different from deterministic as compared to the statistical approach. While deterministic methods start first with the computation of sensitivity (which are subsequently used, among other things, to propagate uncertainty from input parameters to output quantities), the statistical methods compute response uncertainties first (and estimate sensitivities subsequently). Today statistical methods are rather "divorced" from deterministic methods. The deterministic methods currently used provide "local" sensitivities (local in scope), while statistical methods tend to be global in scope, but can miss nevertheless important critical points such as maxima, minima and bifurcations. Combining the features of statistical and deterministic methods (e.g., providing partial sensitivities through adjoints representing importance functions), and matching the two methods are important tasks for future research developments. Within the 6th EU FP the NURESIM, one subject covers combining the statistical and deterministic methods for the new reactor simulation to be developed within this software platform.. Also the JRC-Ispra has expressed the intention to contribute to an integration of the statistical and deterministic methods. These tools should be "global" in the sense that they would not miss the important points. This process should also lead to the standardization of the software tools used in nuclear industry.

Historically, systematic methods for SA/UA were first developed within the nuclear community (Manhattan Project). Many of the pioneers have since retired and the knowledge was not passed on directly to the next generation. Many important papers on this topic were published in the 1970s, and should be revisited. The topic of SA/UA was further developed by geophysicists and weather / climate scientists particularly in the 1990s, when many publications (on both deterministic and stochastic methods) were published by the geophysics sciences community. Their major progress was in "data assimilation", a procedure that is similar to the data adjustment (formulated in the 1970s) in nuclear applications. Through this method, the predictability was increased (e.g. from 2 to 5 days in weather forecasting) and their tools were standardized. In order to better familiarize the "nuclear sciences & engineering" community with the advances reached in the geophysical sciences community, it is suggested to invite experts from "data assimilation" in future meetings. Progress has been achieved also in the Chemistry area.

A. de Crécy

The quantification of the uncertainties of the input parameters for probabilistic approaches was presented based on lessons learned from the CSNI BEMUSE project. A benchmark focussed on this issue should be defined consisting of choosing a rather simple experiment with a limited number of uncertain input parameters and without providing its results. The list of uncertain parameters or at least the phenomena to be considered should be provided, together with a common input deck, for a widely used system code such as RELAP5 Mod3.3 and complemented by a large number of explanations so that the translation of this input deck into other codes is easy. The aim would be to minimize the user's effect. Each participant should then estimate the sPDF of the input parameters. As for expert judgment it should be formalised by describing how the experts give their estimations, the confidence they have in their estimations, how the experts are selected, how they are "managed", etc. This item seems especially important because expert judgement is broadly used, but generally without a lot of explanation. As for the analysis of the experiments, the description of the method with its hypotheses and limitations should be provided, as well as the list of the SET experiment considered for each input parameter. Finally the

uncertainty analysis with the same method should be performed. The uncertainty bands must envelop the experimental data, without being too large

V. Boyarinov

An ISTC project on the "Analysis of the Methodological Part of Uncertainty of Neutron Physics Calculation of Transient Processes for Next Generation Reactors and Fuel Cycles" was presented. This aims at identifying

- the influence of uncertainties in the analyses and comparisons of innovative technologies and technological decisions
- the uncertainties in concomitant accidents, e.g. LOCA together with RIA
- the uncertainties connected with residual heat (dispersion of radio-nuclides in accidents)
- establishing the requirements for the uncertainties of safety parameters and planning of experiments
- identifying the components of uncertainties and their requirements

E. Sartori

A proposal was presented for a comparison and consistency analysis of data sensitivity profiles from different methods (using experimental benchmarks - SNEAK-7A & 7B). The uncertainty covariance matrices would be provided to participants in 15 groups. This would contribute to clarify some of the discrepancies found using different methods. The proposal was made on behalf of CNAM and CNRS Orsay, France

S. Langenbuch

Effort concentrates on uncertainty methodologies applied to thermal-hydraulic problems, but we need more applications addressing the neutronics field, such as coupled code applications and criticality safety: how is the determination of relevant parameters affected by uncertainty? For design basis accidents, such as RIA, MSLB UA/SA should be applied. Uncertainty methods are available for practical applications, but they can be improved through their use and after gaining more experience for relevant problems. When sufficient experience is available, such methods can be introduced for licensing. It is of importance to find relevant reactor physics problems with feedback from thermal-hydraulics. The UA/SA is of interest both for PWR / BWR.

E.Royer

He agrees with this: the use of these methods should be promoted, they should be introduced systematically as a uncertainty analysis phase in all benchmarks; this will lead to its introduction more generally. Also it is important to look at new methods from other fields. Suggestions:

1) introduce SA/UA in ISP benchmarks
   a) mix expertise in physics and SA/UA
   b) compare and assess the current SA/UA on representative applications (e.g. RIA, MSLB), starting from simple cases, but above all from real life data
2) Enlarge R&D in SA/UA methods
   a) Need for effective and powerful methods suitable for coupled simulations and new computers, 3D transport, CFD, coupled N/TH
   b) Take benefit from different applications
   c) Recommendations and guidelines
   d) Introduce advanced / optimised SA/UA methods in our best estimate reactor simulators.

S. Bajorek

We should design simple benchmarks guiding us to understand uncertainties. Deterministic methods are important and should be retained. UA in the neutronics area is important. The BWR turbine trip would be a good starting point. The questions that need to be answered are:
When is a code accurate enough?
How can statistical methods help us?

A. Santamarina

SA/UA should be extended to analyses beyond criticality (k_eff) and should include all reactivity coefficients, control rod worths, and cycle length. It should be extended to every design parameter, and cover parameters from safety requests. Also the experimental information available needs to be transferred to design parameters.

A.Kereszturi

The subjectivism of the expert judgment concerning the Probability Density Functions (PDFs) of the safety analysis input should be reduced in future step by step. This involves the extension of the sensitivity and uncertainty analysis area in the direction of the core steady state variables (e.g. reactivity coefficients, power peaking factors determined by the core design). Measured data from test facilities and NPP start-up should be utilised in the course of this activity.

K. Ivanov

He summarized the discussion as follows:

- there is a clear interest
- form an expert group on an agreed benchmark
- such a benchmark should contain neutronics and feedback
- Peach Bottom TT would be a good candidate as we have already the model, the experimental data, and the transient data
- also separate effects should be included

J. Aragonés

Summary:

- there is a consensus about the need and timeliness for setting up an expert group
- there is a need for a common language for the different methods,
- there is a need for different methods
- it is recommended to revisit work published in the past (especially as concerns neutronics)
- we should take into account what was done in other areas, in particular using the ideas of data adjustment and assimilation in order to get best estimate results for specific applications – add available experimental integral / special effects data to reduce uncertainties and improve model predictions for the future
- safety related / design codes should provide uncertainty as part of the results
- this work should be carried out closely linked to the benchmarks – “that’s where the ‘meat’ is”; we have a significant set of different problems which allow us to advance in this field
- separate effect tests (e.g. BFBT), uncertainty of some input parameters should be included
- more specific guidelines need to be provided to ensure there are no gaps (e.g. there should be an extension to fuel thermo-mechanics for safety analysis)
- we need to involve utilities and regulators

- as to the time schedule for the next NSC meeting:
  - the terms of reference of the expert group should be prepared
  - the deliverables should be defined
  - the expert group(s) on transients have been discussing and started addressing UA which would fit into their scheme
  - the proposal will be submitted on 1 June 2006 at the annual NSC meeting and discussions with the CSNI groups should take place.

F. D'Auria agreed with the summary and prepared a proposal, together with K. Ivanov, concerning the work programme and steps (exercises) that would be needed to undertake this task (see Annex III). The other proposals made during the meeting would be incorporated under the different steps (exercises) within the overall benchmark framework for an uncertainty analysis of multi-physics (coupled) and multi-scale simulations. Due to the large number of steps, which are linked to each other, it was agreed that more than two years would be required to make a real impact. It was accepted that a group of four experts – F. D'Auria, E. Royer, S. Langenbuch and K. Ivanov - will finalize the proposal as shown in Annex III, which will be presented for endorsement to the June meeting of NSC, NEA, by J. Aragones.

Participation in the proposed benchmark exercise

Wide interest was shown and participation (to be confirmed) will be from GRS(Germany), FZK (Germany), FZR (Germany), KFKI (Hungary), U.Pisa (Italy), CEA (France), TEPCO (Japan), Gidropress (Russia), KIAE (Russia), UPM (Spain), NRC (USA), PSU (USA), EC-JRC, etc.

Proceedings

The main results of the meeting and proposals for future activities will be presented to the NSC at the June 2006 meeting. Copies of presentations on CD-ROM will be distributed free of charge to all participants after the meeting.

Relevant Seminars, Training and Conferences

– The 6th Seminar and Training on Scaling, Uncertainty and 3D Coupled Code Calculations in Nuclear Technology (3D SUNCOP) is scheduled from 22 January to 9 February 2007 at the Department of Nuclear Engineering of Texas A&M, College Station, Texas, USA
– From 18 to 22 June 2007, the SAMO-2007 (Sensitivity Analysis on Model Output) Conference is scheduled in Budapest.

Next meeting

Because the SA/UA is strongly linked to ongoing benchmarks, it was found that a synergy would be achieved by holding the next meeting in conjunction with the V1000CT5 meeting and the BFBT4 meeting, from 10 to 11 May 2007, in Paris, to be hosted by the NEA/OECD and CEA-Saclay.

Annex I

Uncertainty Analysis in Modelling
(UAM-2006)

Pisa, Italy
28-(29 am) April 2006

Hosted by: University of Pisa

FINAL PROGRAMME [01]

Opening Session (Chairs: J. Aragonés, F. D'Auria, E. Sartori)

- Introduction and Welcome
- Objective of the meeting [00]
- Introduction of Participants [02]

Session 1 – The Current Uncertainty (and Sensitivity) Analysis Methods Covering: Main Characteristics of the Methods and Implementations, Range of Applicability and Examples of Applications Issues and Limitations of Current Methods.

Chairs: F. D'Auria, S. Langenbuch

- *F. D'Auria, A. Petruzzi: "The origin of Uncertainty and Topic Relevant for Uncertainty Evaluation (TRUE)" [03a], Background[03b]*
- *S. Tarantola, A. Saltelli: "Methodologies for Global Sensitivity / Uncertainty Analysis"[04]*
- *B.Krzykacz-Hausmann, S.Langenbuch "Outline of the GRS Methodology for Uncertainty and Sensitivity Analysis" [05a], Background paper [05b]*
- *R. Bolado, J. Carlsson: Uncertainty and Sensitivity Methods for the Design and Safety Assessment of Nuclear Reactors: Example of Application [06]*
- *Petruzzi, F. D'Auria:" The Code with the Capability of Internal Assessment of Uncertainty (CIAU): Main Features and Key Applications".[07]*
- *S. Langenbuch: "Application of Uncertainty and Sensitivity Analysis Methods for Plant Transients" [08]*
- *Agnes de Crecy, Pascal Bazin: "The BEMUSE programme: part uncertainty and sensitivity analyses of the LOFT L2-5 experiment" [09a], proposal for "Uncertainty Analysis : Quantification of the uncertainties of the input parameters for probabilistic approaches [09b]*
- *Santamarina: Reduction of Calculation Error and Uncertainty Using Mock-up Experiments. Application in the Safety-Criticality Package CRISTAL. [10]*

Session 2 – Needs for Improvements in Current and/or for New Advanced U&S Analysis Methods

Chairs: K.N. Ivanov, E. Royer

i) Identify the Improvements in Current U&S Methods and the R&D Efforts needed
ii) Identify the New Advanced Methods for U&S and the R&D Efforts needed
iii) Evaluate the Previous Alternatives and set Priorities
iv) Available Tools in the Public Domain

- *Jinzhao Zhang : Utility's Perspectives on the Application of Statistical Uncertainty Analysis Methods [11]*
- *Jiri Macek: Uncertainty Methodology and Best Estimate Methods for VVER Reactors [12]*
- *P.N. Alekseev, V.F.Boyarinov: Problem of Defining the Requirements for Calculational Prediction Uncertainty of Important Functionals in Operational Coupled and Transient Processes for Reactors of Different Types [13]*
- *P.N. Alekseev, V.F.Boyarinov: Brief presentation of project proposal "Analysis of the Methodological Part of Uncertainty of Neutron-Physics Calculation of Transient Processes for Next Generation Reactors and Fuel Cycles" (10 minutes)[14a],[14b]*
- *F. Gaudier and JM Martinez; "Uncertainty Analysis from Surrogate Model and Polynomial Chaos" [15]*
- *V. Mastrangelo, I. Kodeli, E. Sartori: Proposal of a Benchmark for Stochastic and Deterministic Analyses of Nuclear Data Sensitivities and Uncertainties[16]*
- *E. Sartori, I. Kodeli: Sensitivity / Uncertainty Analysis Tools Available from the OECD/NEA Data Bank and Ongoing Efforts in the Neutronics Area. [17]*

<u>Session 3</u> – Experts Round-Table on Integration of Methods Deriving from Previous R&D Efforts within NSC and CSNI Scopes, Proposals

Chairs: D. G. Cacuci, J. Aragonés, E. Sartori

i) Level or stage of the required R&D efforts: scientific (NSC), qualification for safety applications (CSNI), Proposals of co-ordination and actions for the NSC and CSNI: scope and time-schedule.

ii) Participants' Proposals.
   - Proposal presented by G. D'Auria on "Uncertainty in nuclear systems and processes and their combination" (see Annex III)
   - Conclusions and Report to NSC (on June 1st meeting)
   - Closing remarks

Annex II

UAM-2006 List of Participants

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Annex II

OECD/NEA/NSC BENCHMARK PROPOSAL
Pisa, April 28-29, 2006

Title: Uncertainty analysis in the coupled multi-physics and multi-scale LWR modelling.

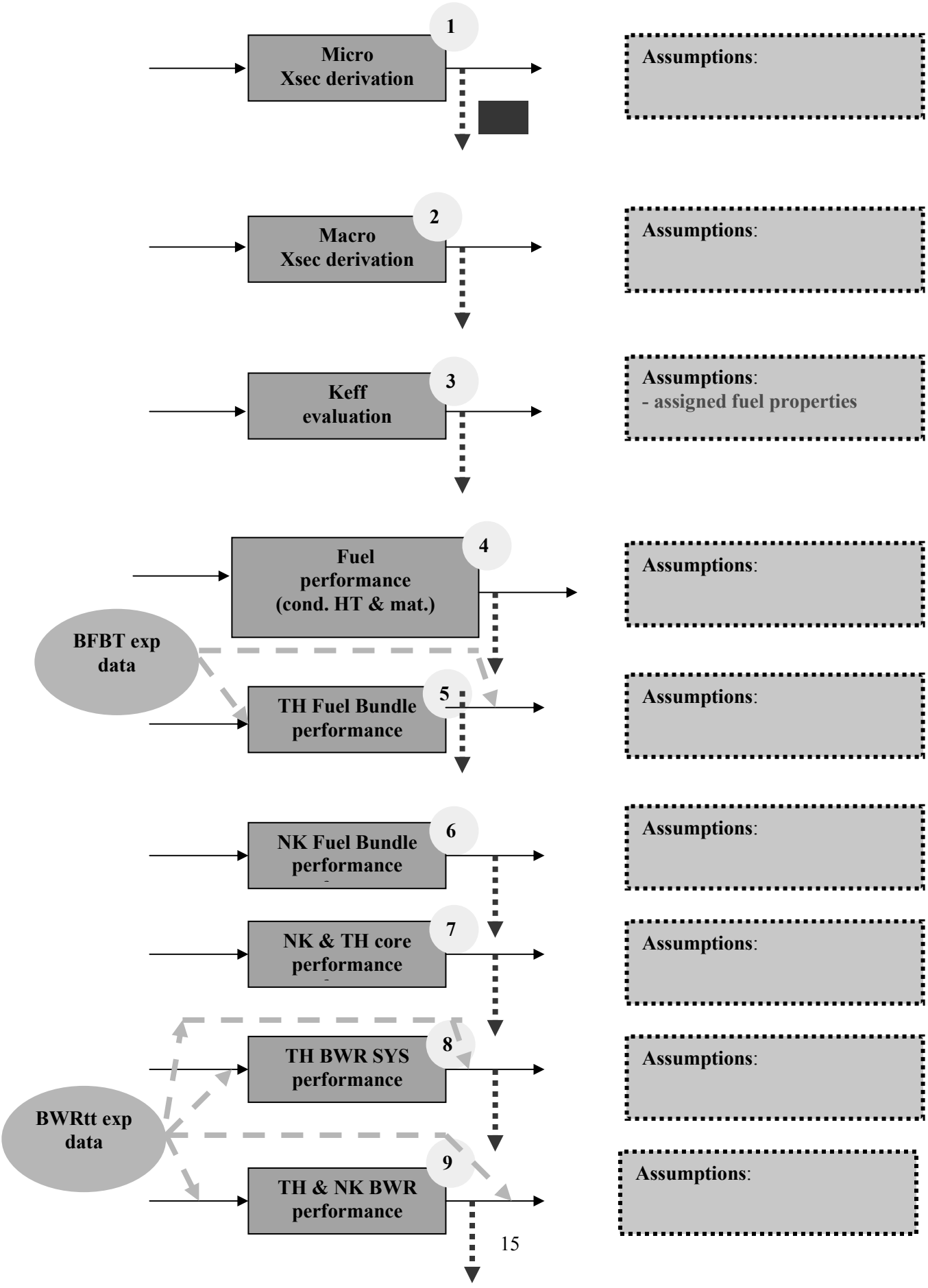
Objective: To determine the uncertainty in LWR systems and processes in all stages of calculations

Reference system and scenario: PB BWRTT (or another one if needed, like MSLB-TMI-1, PWR-RIA-ATWS, Kalinin-3, VVER-1000, etc.)

The idea: a) to subdivide the complex system/scenario into several steps, b) to identify input, output and assumptions for each step, c) to calculate the uncertainty in each step; d) to propagate the uncertainty for the evaluation of the overall system/scenario.

Additional notes:

1) The process is depicted in the following figure.
2) It is recommended to use experimental data as much as possible (two "interactions" with 'known' experimental data are indicated by green blocks, but others can be added).
3) The Host Institution shall identify Input (I), Output (O) or target of the analysis, as well as assumptions for each step and target uncertainty parameters (U).
4) The uncertainty from one step should be propagated to the others (as much as feasible and realistic).


1
Micro
Xsec derivation
Assumptions:
2
Macro
Xsec derivation
Assumptions:
3
Keff
evaluation
Assumptions:
- assigned fuel properties
4
Fuel
performance
(cond. HT & mat.)
Assumptions:
BFBT exp
data
5
TH Fuel Bundle
performance
Assumptions:
6
NK Fuel Bundle
performance
Assumptions:
7
NK & TH core
performance
Assumptions:
8
TH BWR SYS
performance
Assumptions:
BWRtt exp
data
9
TH & NK BWR
performance
Assumptions: