Nuclear Safety
NEA/CSNI/R(2013)8
September 2013
www.oecd-nea.org

OECD/CSNI Workshop on Best Estimate Methods and Uncertainty Evaluations

Workshop Proceedings
Barcelona, Spain
16-18 November 2011

Part 1

OECD
BETTER POLICIES FOR BETTER LIVES

NEA
NUCLEAR ENERGY AGENCY

Unclassified **NEA/CSNI/R(2013)8/PART1**

Organisation de Coopération et de Développement Économiques
Organisation for Economic Co-operation and Development **28-Nov-2013**

English text only

NUCLEAR ENERGY AGENCY
COMMITTEE ON THE SAFETY OF NUCLEAR INSTALLATIONS

NEA/CSNI/R(2013)8/PART1
Unclassified

OECD/CSNI Workshop on Best Estimate Methods and Uncertainty Evaluations

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Hosted by the Technical University of Catalonia (UPC) with support from the Spanish Nuclear Safety Council (CSN)

JT03349504

Complete document available on OLIS in its original format

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ORGANISATION FOR ECONOMIC CO-OPERATION AND DEVELOPMENT

The OECD is a unique forum where the governments of 34 democracies work together to address the economic, social and environmental challenges of globalisation. The OECD is also at the forefront of efforts to understand and to help governments respond to new developments and concerns, such as corporate governance, the information economy and the challenges of an ageing population. The Organisation provides a setting where governments can compare policy experiences, seek answers to common problems, identify good practice and work to co-ordinate domestic and international policies.

The OECD member countries are: Australia, Austria, Belgium, Canada, Chile, the Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Israel, Italy, Japan, Luxembourg, Mexico, the Netherlands, New Zealand, Norway, Poland, Portugal, the Republic of Korea, the Slovak Republic, Slovenia, Spain, Sweden, Switzerland, Turkey, the United Kingdom and the United States. The European Commission takes part in the work of the OECD.

OECD Publishing disseminates widely the results of the Organisation’s statistics gathering and research on economic, social and environmental issues, as well as the conventions, guidelines and standards agreed by its members.

NUCLEAR ENERGY AGENCY

The OECD Nuclear Energy Agency (NEA) was established on 1 February 1958. Current NEA membership consists of 31 countries: Australia, Austria, Belgium, Canada, the Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Japan, Luxembourg, Mexico, the Netherlands, Norway, Poland, Portugal, the Republic of Korea, the Russian Federation, the Slovak Republic, Slovenia, Spain, Sweden, Switzerland, Turkey, the United Kingdom and the United States. The European Commission also takes part in the work of the Agency.

The mission of the NEA is:

– to assist its member countries in maintaining and further developing, through international co-operation, the scientific, technological and legal bases required for a safe, environmentally friendly and economical use of nuclear energy for peaceful purposes, as well as

– to provide authoritative assessments and to forge common understandings on key issues, as input to government decisions on nuclear energy policy and to broader OECD policy analyses in areas such as energy and sustainable development.

Specific areas of competence of the NEA include the safety and regulation of nuclear activities, radioactive waste management, radiological protection, nuclear science, economic and technical analyses of the nuclear fuel cycle, nuclear law and liability, and public information.

The NEA Data Bank provides nuclear data and computer program services for participating countries. In these and related tasks, the NEA works in close collaboration with the International Atomic Energy Agency in Vienna, with which it has a Co-operation Agreement, as well as with other international organisations in the nuclear field.

THE COMMITTEE ON THE SAFETY OF NUCLEAR INSTALLATIONS

"The Committee on the Safety of Nuclear Installations (CSNI) shall be responsible for the activities of the Agency that support maintaining and advancing the scientific and technical knowledge base of the safety of nuclear installations, with the aim of implementing the NEA Strategic Plan for 2011-2016 and the Joint CSNI/CNRA Strategic Plan and Mandates for 2011-2016 in its field of competence.

The Committee shall constitute a forum for the exchange of technical information and for collaboration between organisations, which can contribute, from their respective backgrounds in research, development and engineering, to its activities. It shall have regard to the exchange of information between member countries and safety R&D programmes of various sizes in order to keep all member countries involved in and abreast of developments in technical safety matters.

The Committee shall review the state of knowledge on important topics of nuclear safety science and techniques and of safety assessments, and ensure that operating experience is appropriately accounted for in its activities. It shall initiate and conduct programmes identified by these reviews and assessments in order to overcome discrepancies, develop improvements and reach consensus on technical issues of common interest. It shall promote the co-ordination of work in different member countries that serve to maintain and enhance competence in nuclear safety matters, including the establishment of joint undertakings, and shall assist in the feedback of the results to participating organisations. The Committee shall ensure that valuable end-products of the technical reviews and analyses are produced and available to members in a timely manner.

The Committee shall focus primarily on the safety aspects of existing power reactors, other nuclear installations and the construction of new power reactors; it shall also consider the safety implications of scientific and technical developments of future reactor designs.

The Committee shall organise its own activities. Furthermore, it shall examine any other matters referred to it by the Steering Committee. It may sponsor specialist meetings and technical working groups to further its objectives. In implementing its programme the Committee shall establish co-operative mechanisms with the Committee on Nuclear Regulatory Activities in order to work with that Committee on matters of common interest, avoiding unnecessary duplications.

The Committee shall also co-operate with the Committee on Radiation Protection and Public Health, the Radioactive Waste Management Committee, the Committee for Technical and Economic Studies on Nuclear Energy Development and the Fuel Cycle and the Nuclear Science Committee on matters of common interest."

1. EXECUTIVE SUMMARY

1.1 Background

Best-Estimate Methods plus Uncertainty Evaluation are gaining increased interest in the licensing process. On the other hand, lessons learnt from the BEMUSE (NEA/CSNI/R(2011)3) and SM2A (NEA/CSNI/R(2011)3) benchmarks, progress of UAM benchmark, and answers to the WGAMA questionnaire on the Use of Best-Estimate Methodologies show that improvements of the present methods are necessary and new applications appear. One can quote:

- For BEMUSE user effect for base case calculations, user effect for the uncertainty method application and the need for developing methods to estimate input parameter and model key parameter uncertainties.
- For UAM, concerns are on how to subdivide the complex system of coupled multi-physics and multi-scale simulations into different steps, to derive multi-group microscopic cross-section libraries and how to proceed to calculate the uncertainties in further steps.
- For SM2A, which addressed other scenarios than LBLOCA, other physical model uncertainty may be of concern; also, probability distribution to characterize time delay for system recovery or for a repair may be of high importance as the sequences including such time delays could be impacted by power up-rate;
- Examples of new applications: uncertainty and sensitivity analysis of CFD codes, uncertainties for coupled codes, connection with PSA.

It is recognised that the continuous improvement of classical BEPU approaches as mentioned above, will favour gaining confidence on their use instead of the conservative or mixed conservative-BE approaches. Looking into the future, the application of the BEPU methods to new codes (e.g. CFD) is compulsory to increase the level of confidence of these applications or tools in the nuclear safety field. As computing capacity is expanding, the extension of BEPU methods to coupled codes (e.g. TH-neutronics) and to PSA (refinement of success criteria verification and safety margin assessment) is subject of increased interest in the nuclear safety community.

1.2 Objectives of the workshop

The CSNI Working Group on Analysis and Management of Accidents (WGAMA) objective is to assess and where necessary strengthen the technical basis needed for the prevention, mitigation and management of potential accidents in nuclear power plants, and to facilitate international convergence on safety issues and accident management analyses and strategies.

The objective of this workshop is to provide a forum for a wide range of experts to exchange information in the area of best estimate analysis and uncertainty evaluation methods and address issues drawn-up from BEMUSE, UAM and SM2A activities. Both, improvement of existing methods and recent new developments are included. As a result of the workshop development, a set of recommendations, including lines for future activities were proposed.

1.3 Organization of the workshop

The Workshop was focused on BEPU methods involving thermo-hydraulics for system codes. Other applications, involving CFD, neutronics coupling or extension to PSA, were also be subject of the workshop.

As a common denominator of the Workshop, BEPU methods and applications were exposed and the capacity to determine the preservation of safety margins through a transparent and solid technical basis debated.

The Workshop was open to wider participation especially participants to OECD/CSNI exercises like BEMUSE, UAM, SM2A, to other benchmarks, as well as industrial partners, Technical safety organizations and safety authorities and academia.

The organisation of the Workshop was divided into three parts: Opening session including key notes from OECD and IAEA representatives, Technical sessions, and a Wrap-up session. All sessions included a debate with participation from the audience constituted by 71 attendees.
The workshop consisted of four technical sessions:
a) Development achievements of BEPU methods and State of the Art
The objective of this session was to present the different approaches to deal with Best Estimate codes and uncertainties evaluations. A total of six papers were presented. One initial paper summarized the existing methods; the following open papers were focused on specific methods stressing their bases, peculiarities and advantages. As a result of the session a picture of the current State of the Art was obtained.
b) International comparative activities
This session reviewed the set of international activities around the subject of BEPU methods benchmarking and development. From each of the activities a description of the objectives, development, main results, conclusions and recommendations (in case it is finalized) was presented. This session comprised a total of four papers.
c) Applications: licensing, safety analysis support, regulatory body views and industry activities
This session put the focus on the application of current methods in safety analyses. Contribution from industry, technical safety organizations and regulatory bodies was present. As a result, a view of the penetration of BEPU methods in current safety analyses was obtained, as well as an indication of the evolution in the near future. Elements such as licensing practices, assessment process, etc. were considered. This session comprised nine papers.
d) BEPU methods extension to new fields

Since the early days of BEPU methods development it was realized that this approach could be extended and its benefits applied to other areas beyond the classic deterministic environment. This session was focused on the extension of BEPU methods beyond this point. The session developed the extension to CFD, quantification of global safety margins, use of PSA, etc. with a total of seven papers.

The Technical programme of the workshop is included as appendix I.

1.4 Results

The workshop provided an interesting and useful forum for the participants to share and discuss their respective practices regarding BEPU methods and state-of-the-art, BEPU applications in the licensing, safety analysis support, regulatory body views and industry activities, as well as BEPU extension to new fields such as safety margin evaluation and CFD.

The workshop discussions indicated that there is currently consensus on the maturity of BEPU as applied to accident analysis with system computer codes while a wide spectrum of views might exist in other new areas like handling of uncertainties in coupled codes, extension of BEPU methods to PSA environment, etc. The discussions also highlighted key technical and regulatory issues requiring further work like management of residuals e.g. failed 5/95 cases, implications on Technical Specifications definition, etc.

The followings summarize key points of the presentations and discussions provided during the workshop:

- Model uncertainties quantification was mentioned by different authors and also was the concern in different discussions. Such quantification was recognized as an activity worth of the current effort of the research community (CSNI/PREMIUM project).

1. *It is recommended to pursue in the efforts to achieve a consensus on the methods of quantification of input epistemic uncertainties and their treatment. PREMIUM project will contribute to solve this problem.*

- OECD projects from the past like UMS and BEMUSE along with the on-going ones UAM and PREMIUM were presented as a consistent movement leading to consecutive improvements in the consolidation of BEPU methods. Uncertainty related to multi-physics analyses (currently addressed in UAM and other NSC benchmarks) will require additional attention.

2. *It is recommended that future analytical or experimental activities include an evaluation of input & output uncertainties.*

- The feasibility of implementing BEPU methods in the different new areas of safety analysis was also presented. Participants emphasized the need of further research and pilot applications especially in these new areas as a way to advance in the future application in safety analysis.

3. *It is recommended to promote the extension of BEPU methods into other safety analysis areas like: fuel behavior, subchannel analysis, neutronics, and their coupling. NEA/NSC UAM project will provide relevant results on this subject. Pilot applications as a proof of concept should be favored.*

- A certain number of papers showed that powerful methods exist for plant safety verification purposes i.e.: comprehensive evaluation of global plant safety performance against postulated internal and external events. They advance into the integration of probabilistic and deterministic views in a consistent way. In view of the recent Fukushima accident, it is asserted that progress into integrated methods for safety verification is a need.

4. *It is recommended to promote the advance into the development of deterministic/probabilistic methods for safety verification purposes. The use of pilot applications should be considered in order to check the benefits and potentials of this approach.*

- The importance of validating BEPU methods and of reducing user effects was also an implicit conclusion of several presentations. Benchmarking exercises like BEMUSE have shown that large scatter among the different participants are present, casting doubts with regard the application of the method in licensing. Although BEPU methods have been used in increasing number for licensing, it was also observed that some of their aspects (especially evaluation of the safety margin) may present challenges to some regulators.

5. *It is recommended to pursue into the validation of BEPU methods in order to answer regulatory concerns.*

- It was observed that under the so called IAEA/SSG-2 Option 4, design basis analysis and design bases extension analyses can benefit from full application of BEPU methods together with credit to systems availability. At the moment this approach is in first steps and needs further development. A potential for a new design bases standard was acknowledged.

6. *It is recommended to advance into the development works and potential safety benefits outcome of BEPU methods application with consideration of systems availability (*option 4*)*

The recommendations of the workshop can be summarized by emphasizing that a great advance has been achieved since the beginning of BEPU activities, pointing to the consolidation of practices and nevertheless identifying still pending concerns. While the added value to safety with origin in the use of BEPU methods is recognized, the full potential of BEPU approach to a comprehensive safety assessment is still pending with regard to development. The CSNI and other international organizations like IAEA should play a leading role in this advancement.

2. ADVISORY BOARD

An Advisory Board was formed by extending the Scientific Committee (see announcement) with the chairpersons of each session.

The Advisory Board organised the sessions, the paper review and the final summary for the workshop. The following persons form the Advisory Board:

Abdallah Amri	OECD/NEA		Secretariat
Francesco D'Auria	UNIPI	Italy	
Steve Bajoreck	NRC	USA	
Agnes De Crecy	CEA	France	
Milorad Dusic	IAEA		
Horst Glaeser	GRS	Germany	
Rafael Mendizabal	CSN	Spain	
Fernando Pelayo	CSN	Spain	
Francesc Reventos	UPC	Spain	Chair
Tomasz Skorek	GRS	Germany	

3. SUMMARY OF TECHNICAL SESSIONS

3.1 Technical Session 1: Development achievements of BEPU methods and State of the Art

The objective of this session was to present the different approaches dealing with Best Estimate codes and uncertainties evaluations. Existing methods were summarized and different papers were focused on specific methods stressing their bases, peculiarities, advantages and limitations. As a result of the session a picture of the current State of the Art was obtained.

3.1.1 Summary of session 1 papers

The session comprised six papers.

Paper S1.1: "Summary of existing uncertainty methods", presented by H. Glaeser (GRS)

In the first paper, a summary of existing and most used uncertainty methods was presented and the main features were compared. The most popular of these methods is the order statistics method based on Wilks' formula. It is applied in safety research as well as in licensing. This method has been first proposed by GRS for use in deterministic safety analysis, and is now used by many organisations world-wide. Its advantage is that the number of potential uncertain input and output parameters is not limited to a small number. Such a limitation was necessary for the first demonstration of the Code Scaling Applicability Uncertainty Method (CSAU) by the United States Regulatory Commission (USNRC). This first demonstration did not apply Wilks' formula in the statistical method propagating input uncertainties to obtain the uncertainty of a single output variable, like peak cladding temperature. A Phenomena Identification and Ranking Table (PIRT) was set up in order to limit the number of uncertain input parameters, and consequently, the number of calculations to be performed. Another purpose of such a PIRT process is to identify the most important physical phenomena which a computer code should be suitable to calculate. The validation of the code should be focussed on the identified phenomena. Response surfaces are used in some applications replacing the computer code for performing a high number of calculations.

The third well known uncertainty method is the Uncertainty Methodology Based on Accuracy Extrapolation (UMAE) and the follow-up method "Code with the Capability of Internal Assessment of Uncertainty (CIAU)" developed by the University Pisa. Unlike the statistical approaches, the CIAU does compare experimental data with calculation results. It does not consider uncertain input parameters. Therefore, the CIAU is highly dependent on the experimental database. The accuracy gained from the comparison between experimental data and calculated results are extrapolated to obtain the uncertainty of the system code predictions for a nuclear power plant. A high effort is needed to provide the data base for deviations between experiment and calculation results in CIAU. That time and resource consuming process has been performed only by University of Pisa for the codes CATHARE and RELAP5 up to now.

The other papers presented in this session deal with methodologies, which have been developed recently or are still under development.

Paper S1.2 “Information Synthesis in Uncertainty Studies: Application to the Analysis of the BEMUSE Results” presented by J. Baccou (IRSN).

In this presentation, a methodology for information synthesis from different uncertainty analyses using different codes and implying different experts was explained. The developments performed at IRSN and related to the construction of formal tools to synthesize uncertainty margins coming from multiple sources of information were presented. They are based on probability or possibility theory. They allow one to quantify the quality (exactness and precision) of the provided information and to combine all the information sources in order to exhibit some common features or detect possible conflicts between them. The tools were applied in the frame of the BEMUSE Project for the synthesis of Zion reactor uncertainty analyses. It appeared that the information given by all participants is highly conflicting for the four outputs of interest (first and second peak cladding temperature, injection and quenching time). Considering sub-groups of participants has increased the coherence of the results related to the temperature, what was not the case for time variables. Each sub-group has been identified according to the quality of given information or with respect to the used computer code. In this case the effect of the code, which is significant, should be emphasized.

Paper S1.3: “Generic application of Wilks´ tolerance limit evaluation approach to nuclear safety” presented by In Seob Hong (KINS).

In this presentation the generic application of Wilks’ tolerance limit evaluation approach to nuclear safety was analysed. The presentation was focused on discussion of a better application of Wilks’ formula based approach by presenting applicable tables and supporting numerical simulation results which were followed by summary and presentation of the Wilks’ one side and two side formulas. The authors tried to gain an in-depth understanding of the Wilks’ set of formulas: one-side and two-side and suggested some considerations to be taken into account for more appropriate application to the nuclear safety field.

Paper S1.4 “An Integrated Approach for Characterization of Uncertainty in Complex Best Estimate Safety Assessment” presented by Mohammad Modarres (Maryland University)

In this presentation an approach called Integrated Methodology for Thermal-Hydraulics Uncertainty Analysis (IMTHUA) to characterize and integrate a wide range of uncertainties associated with the best estimate models and complex system codes used for nuclear power plant safety analyses was discussed. In identifying and assessing uncertainties, the proposed methodology treats the complex code as a “white box”, thus explicitly treating internal sub-model uncertainties in addition to the uncertainties related to the inputs to the code. The methodology accounts for uncertainties related to experimental data used to develop such sub-models, and efficiently propagate all uncertainties during best estimate calculations. Uncertainties are formally analysed and probabilistically treated using a Bayesian inference framework. The approach includes provisions to account for uncertainties associated with user-specified options, for example for choices among alternative sub-models, or among several different correlations. The presentation was focused on methods of input uncertainties quantification via the Maximum Entropy and expert judgement conditioned on availability and type of information.

Paper S1.5 “Supporting database for uncertainty evaluation” presented by Fabio Veronese (UNIPI).

This paper discusses the role and the depth of analysis required for merging from one side suitable experimental data and on the other side qualified code calculation results. The paper presents the features and structure of the data base that includes a series of documents whose goal is to demonstrate the qualification level of the achieved code results. This aspect is mostly connected with a Best Estimate Plus Uncertainty analysis based on “propagation of code output errors” approach. Such qualified data base is a fundamental pillar to justify the quantification level of the error data base, but its availability should be also a mandatory requirement for any analysis based on best estimate approach. By-product of this activity is the concrete possibility to make traceable any input’s value and any user choice respectively derived and taken from the blue prints to the final achieved code results

Paper S1.6 “A procedure for characterizing the range of input uncertainty parameters by the use of FFTBM” presented by Fabio Veronese (UNIPI).

The last presentation in the session of dealt with a procedure for characterizing the range of input uncertainty parameters by the use of the FFTBM in the place of the approaches based mostly on engineering judgement. The procedure is based on the use of the Fast Fourier Transform Based Method (FFTBM), already part of the Uncertainty Method based on the Accuracy Extrapolation (UMAE). The FFTBM allows a quantitative judgement for a given calculation. Each set of two curves constituted by a calculated and a measured time trend can be processed by FFTBM. The transformation from time to the frequency domain avoids the dependence of the error from the transient duration. Weight factors are attributed to each time trend to make possible the summing up of the error and the achievements of a unique threshold for accepting a calculation. The quantitative accuracy evaluation by FFTBM must be carried out following the demonstration that the calculation is qualitatively acceptable.

3.1.2 Generic discussion from session 1

The session managed to fulfill its goal by reviewing and summarizing the current State of the Art basically following the contents of the first presentation while other specific topics were treated in different presentations. In this sense the arisen discussions were basically devoted to clarify benefits, drawbacks and constrains of the presented methods and validation tools including output evaluation.

Among the subjects that arose the interest of the audience, the following could be mentioned:

- Consideration and treatment of the measurement error by evaluation of model uncertainties
- Two-steps hybrid input – output based uncertainty assessment
- Method for information synthesis
- Dependence between data base and code
- Uncertainty evaluation on the basis of more complex experiments than the separate effect tests

During the subsequent debates it was emphasized from the audience the quality of uncertainty analysis in mainly dependant on identification and quantification of input uncertainties and quality of so called qualified input data for the best estimate reference calculation. The importance of the input uncertainties definition was also stressed as it is generally accepted.

The consideration and treatment of the measurement error by evaluation of model uncertainties arose interest of the audience. The single model uncertainty treatment was explained. The presentation of the aspects of the two-steps hybrid input – output based uncertainty assessment was limited to the comparison of some calculated and measured results of an integral experiment, only. Such comparisons are widely used and the merit of the announced hybrid method in contrast to other approaches would be desirable to explore.

Information synthesis methods for results from BEPU assessments were valued as a relevant issue in order to qualify the results. Limitation to only scalar output quantities, like peak cladding temperature for instance, was pointed out as a drawback and hence extension to vector output quantities desirable.

The quality and validation of database for uncertainty evaluation was stressed as a basic element of BEPU methods. The evaluation of the level of the dependency of the output to the quality of the input database could benefit from information synthesis methods.

As a final item of debate it was the characterization of the range of input parameters which raised a considerable interest, since it coped with a live issue of input uncertainties quantification. The presented methodology gives a possible way to quantify uncertainties on the basis of more complex experiments than the separate effect tests. This is still a challenging issue and the presented method could contribute to the solution of the problem.

All these subjects were presented and discussed and in a certain way they help to complete the announced general State of the Art.

3.2 Technical Session 2. International comparative activities

This session had as a main objective to review the activities launched in the past and present from the NEA in connection with BEPU methods, with focus on the applicability of conclusions derived from former benchmarks like UMS, the main outcomes of the recently finished BEMUSE project, and the objectives and relevance of UAM and PREMIUM projects.

The session comprised four papers.

3.2.1 Summary of session 2 papers

Paper S2.1 "The Findings from the OECD/NEA/CSNI UMS (Uncertainty Method Study)" presented by F.D'Auria (UNIPI).

This paper reviewed the UMS main outcomes as well as some results from post-UMS calculations.

UMS was an application of BEPU methods exercise to a 5% SB-LOCA in the LSTF facility. It was the first benchmark on the subject and methods at that time were at some development stage. Three different approaches were tested: accuracy extrapolation from UNIPI, deterministic propagation of uncertainties from UKAEA, and Monte Carlo propagation of uncertainty from IRSN, GRS and ENUSA.

The project allowed for the comparison of these methods step by step, as well as to compare the output uncertainties among the participants and against experimental values. In this exercise the participant were free to select the uncertain model parameters.

Large variability among the participants was observed in the uncertainty ranges obtained for the output. This was traced back to the selection, shape and ranges of the input variables. Also of relevance was the accuracy of the reference case. It was later proved that a large part of the wideness of the range for some participants could be originated by the use of a specific version of Relap code. Once this was corrected the results notably changed.

Post UMS calculations were performed by some participants that notably affected the results, mainly because of a better adequacy of the input uncertainty description. In the case of UNIPI the implementation of bifurcation analysis contributed to a better assessment with results in line with MC propagation methods.

The conclusions derived from that benchmark are currently valid and affect the need of verification of code validation, adequacy of the reference case and validity of input probability density functions descriptions. All methods proved to be suitable to perform their intended function.

After the presentation it was debated the adequacy of uncertainty propagation methods to properly manage time uncertainties of the output. Specifically the debate focused on whether it was acceptable to obtain a time uncertainty that is not monotonously increasing. In defense of this it was argued that time uncertainty is driven by uncertainty in input parameters and as such it may change similarly to any other scalar variable uncertainty.

As recognition of the impact of the input probability density functions on the BEPU methods output, it was suggested to revisit UMS benchmark after the completion of PREMIUM and assess the impact on the improvement on the results.

Paper S2.2 "Main Results of the OECD BEMUSE Programme" presented by F.Reventós (UPC)

This paper summarizes the development of BEPU benchmark and stresses the lessons learned and main conclusions, and how these conclusions have been captured in the PREMIUM project.

BEPU was the first benchmark to check different methodologies against an IET (LBLOCA) and against a NPP LBLOCA.

With respect UMS benchmark methods, order statistics and accuracy extrapolation were present. This benchmark was characterized by the large number of participants (12) and the set of nine different codes and versions used.

The main objectives were to verify the practicability, quality, reliability of BEPU, as well as to promote and facilitate the use by regulatory bodies and industry. Also of importance it was the use of FFTBM (Fast Fourier Transform Based Method) method for accuracy quantification.

The use of agreed pdf for model parameters was recognition of the impact of using different pdf in the scatter of the results among participants and as an important component of the so called user effect. It was also stressed the relevance of the determination of high quality reference case.

It was commented how the influence of the input deck (user effect) may be of the same order as using a different code.

It was also stressed that BEMUSE was not checking what could be a real licensing application and so no bias or other conservative assumptions was introduced in the analysis.

Paper S2.3 "Discussion of OECD LWR Uncertainty Analysis in Modeling Benchmark" presented by K.Ivanov (KIT).

This paper describes the objectives and phases of the program and main outcomes so far derived from the development of phase I of UAM (neutronic phase).

UAM benchmark is divided in three phases named neutronic phase, core phase and system phase. Each phase is divided in a number of exercises, for each exercise, input, output and propagated uncertainty parameters are identified (these last parameters are propagated throughout the follow-up exercises).

The specification for all exercises of phase I has already been finalized

An interesting feature of the UAM project is that it allows addressing all industry issues and participants' interest in PWR, BWR, VVER and MOX fuel.

With regard Phase I the participants have access to SCALE-6.0 covariance library. Some results are shown for pin cell test cases and Keff uncertainty presented.

Multigroup cross sections uncertainties are propagated to few-group cross sections in exercise I.2 (lattice physics) and few-group cross sections are propagated to uncertainties in evaluated stand-alone neutronics core parameters.

Fourteen institutions are participating in phase I.

The obtained output uncertainties from phase I are used in phases II (fuel physics, Time-dependent neutronics, bundle thermal-hydraulics) and phase III (coupled neutronics/thermal-hydraulics, system thermal-hydraulics, coupled core/system and comparison between BEPU calculations vs. conservative calculations.

A detailed relation of expected results of the UAM project is presented as conclusions. Among others: comparison of deterministic, conservative and hybrid methods; recommendations and guidelines for the application of new methods.

UAM benchmark will give us a chance to verify the ability to use BEPU method or adapted hybrid methods in coupled neutronic-fuel–subchannel-system codes to provide uncertainty statements on safety variables. It will provide a measure of the conservativeness of current deterministic methods against BEPU n-TH system codes.

Paper S2.4 “PREMIUM – Benchmark on the quantification of the uncertainty of the physical models in the system thermal-hydraulics codes” presented by T.Skorek (GRS).

PREMIUM is the acronym of “Post BEMUSE Reflood Models Input Uncertainty Methods” and is a benchmark promoted from CSNI’s GAMA group. It is aimed at evaluating methods suitable for quantifying uncertainties in model parameters in TH codes.

The paper is focused on the scope and methods to be applied in the benchmark like CIRCE, KIT and FFTBM. The main goal of the benchmark is to compare existing approaches, identify improvements and produce recommendations for the quantification of uncertainties of model for which no single effect test exist.

The benchmark is structured around the reflood phase associated influential phenomena, identification of relevant parameters and initial quantification.

The FEBA/SEFLEX program has been selected as appropriate to analyze heat transfer mechanisms during reflood phase of a LOCA and to apply and derive parameter uncertainties from associated data.

A verification phase is already proposed making use of the PERICLES reflood experiments aiming at verifying the adequacy of the uncertainty ranges obtained in the previous FEBA/SEFLEX tests.

It is stressed that the output of this benchmark will probably consolidate a common approach to determine uncertainty ranges for model parameters for which no single separate effect tests is available or conceivable.

3.2.2 Generic discussion from session 2

There is a clear continuity between UMS and BEMUSE in which LOCA scenarios were explored under uncertainty analysis techniques. The conclusions derived from both benchmarks where consistent and stressed the need for a good reference case, an eligible code with high enough accuracy, and well characterized uncertain inputs. The methods applied resulted in reasonably similar results. Main differences seem to arise indirectly from user effects.

UAM will largely explore and increase the applicability of BEPU methods to coupled codes. It will be important to check the robustness of the methods in large scale analysis. Potential hybrid methods may arise. It is advisable for UAM to apply lessons learnt from UMS and BEMUSE, and possibly benefit from PREMIUM.

Once BEMUSE is finished, only UAM remains as the only benchmark exercising BEPU methods within NEA. It is advisable to incorporate BEPU analysis in the current or future experimental projects like PKL-2 and or extend the application of BEPU methods to the experimental data base originated from ROSA project. This would allow accumulating experience and gaining confidence.

With regard PREMIUM project there was a general consensus on the relevance and opportunity to join a project that will contribute to fill the gap related to the obtaining of the probability distribution function for model parameters.

3.3 Technical Session 3. Applications: Licensing, safety analysis support, regulatory body views and industry activities

This session focused on the application of current methods in safety analyses. Contributions from industry, technical safety organizations and regulatory bodies were provided. As a result, a view of the penetration of BEPU methods in current safety analyses was obtained, as well as an indication of the evolution in the near future. Elements such as licensing practices, assessment process, etc. were considered

3.3.1 Summary of session 3 papers

The session comprised nine papers

Paper S3.1: "Use and application of best estimate plus uncertainty methods. A regulatory view", presented by F. Pelayo (CSN).

This paper is a regulatory survey about "best estimate plus uncertainty" (BEPU) methodologies. It provides a summary of nuclear regulation, focused on safety principles, which ultimately leads to the licensing bases and design bases of nuclear plants.

The paper describes the evolution from classical conservative deterministic safety analysis to BEPU in licensing practice. Use of BEPU methods needs to accept a probability and confidence statement for meeting regulatory acceptance criteria and determining margins. In fact, a probabilistic definition of safety margin is a logical consequence of the current BEPU approach.

Some topics about BEPU methods are discussed. A focus is put on the impact of BEPU methods on Technical Specifications of a nuclear power plant. The importance of determining distributions of uncertain model parameters of computer codes as well as the validation of uncertainty methods against IET are stressed.

Paper S3.2: "Uncertainty Methods Development for the TRACE Thermal-Hydraulics Code by the U.S.NRC", presented by S. Bajorek (NRC)

The use of order statistics within the CSAU framework is described, in the context of the development of an independent BEPU methodology by the USNRC. It is a methodology for LOCA-ECCS analysis, based on TRACE code and conceived as a tool for auditing BEPU calculations of the industry. To implement the method in an efficient manner, the Symbolic Nuclear Analysis Package (SNAP) has been modified to perform a Monte Carlo sampling of code input parameters, submit multiple calculations, and statistically evaluate the results. SNAP uses the statistical analysis of DAKOTA (Design and Analysis Toolkit for Optimization and Terascale Applications). This is a software package developed by the Sandia National Laboratories specifically for uncertainty and sensitivity analysis. Both plant input parameters and code model parameters can be ranged. Most plant types of interest to the NRC can be evaluated. A proposed list of important uncertain model parameters with ranges and distributions is available in SNAP for different plant and transients. Modifications are possible to add or turn-off parameters and to change the range and distribution.

The methodology will include procedures for local and global sensitivity analyses, and for the fit of surrogate models relating the input parameters to the calculated figures-of-merit (e.g. least squares polynomial regression).

Paper S3.3: "Westinghouse Experience in Licensing and Applying Best-Estimate LOCA Methodologies within the Industry: Past, Present and Future", presented by C. Frepoli (Westinghouse)

The Westinghouse realistic LOCA methodology was updated using the non-parametric statistical method which has become a standard for combining the uncertainties. The "Automated Statistical Treatment of Uncertainty Method" (ASTRUM) was approved by the US NRC in November 2004. Westinghouse applied that method to more than 75% of the Westinghouse PWR fleet in the US and also for several international licensing applications. The use of non-parametric order statistics has been a success story within the industry. Shortcomings, like the residual probability (less than 5%) that the estimate may be lower than the 95% of the population presents some challenges to some regulators. The procedure of performing 124 calculations instead of 59 for three acceptance criteria, and using the sample maxima, reduces the probability of underestimation to 0.2% on a single output. The parameter sensitivities may not be reliable with small sample sizes. Many of these issues can be alleviated by simply increasing the sample size. Westinghouse made several upgrades to come up with a Full Spectrum LOCA (FSLOCA^{TM}) Methodology which is intended to be applicable to a full spectrum of LOCAs, from small to intermediate size break as well as large break LOCAs. It is currently under review by the US NRC.

Paper S3.4: "RELAP5/MOD3.2 Sensitivity Analysis Using OECD/NEA ROSA-2 Project 17% Cold Leg Intermediate-break LOCA Test Data", presented by T. Takeda (JAEA)

A sensitivity analysis was performed using RELAP5/MOD3.2.1.2 calculating an experiment simulating a PWR cold leg intermediate break LOCA with 17% break size. The experiment was performed in the OECD/NEA ROSA-2 Project using the Large Scale Test Facility (LSTF).The post-test analysis revealed that the cladding surface temperature was under-predicted due to later core uncover than in the experiment. For BEPU analysis, key phenomena and related important parameters which affect core liquid level and thus cladding surface temperature were determined. From the single parameter sensitivity analyses, it turned out that both constant C of the Wallis CCFL correlation at the core exit and the gas-liquid inter-phase drag in the core have the highest impact on the cladding temperature. The information from these sensitivity calculations will be used in an uncertainty analysis to be performed in the future.

S3.5: "Towards an industrial application of statistical uncertainty analysis method to multi-physical modeling and safety analyses" presented by Jinzhao Zhang (GDF Suez).

A series of methodologies have been developed to perform and to license the reactor safety analysis and core reload design based on a deterministic bounding approach. Following the recent trends in research, development and industrial applications, Tractebel Engineering (TE) has been working since 2010 on application of the statistical uncertainty and sensitivity analysis methods to the multi-physical modeling and licensing safety analyses. A TE best estimate plus statistical uncertainty analysis method (BESUAM) is described, based on non-parametric order statistics or bootstrap methods. The sensitivity and uncertainty analysis tool DAKOTA is used. Two applications are presented: An OECD RIA fuel rod code benchmark using FRAPCON/FRAPTRAN, and a calculation of a THTF test using RELAP5/MOD3.3.

Order statistics and bootstrap uncertainty analysis have been performed for different sample sizes. The bootstrap estimator using percentile smoothing (based on a Gaussian kernel) approaches the order statistics results, which confirms the robustness of the later. Also, the 95/95 upper tolerance limits (i.e. Wilks' estimators) are compared to the empirical 95 percentiles, and the difference between them is discussed as a criterion for establishing the Monte Carlo sample size.

The study incorporates importance analyses of the inputs, including sensitivities of the results to the distributions chosen for the inputs.

The final objective is to apply the BESUAM method for reloads design and safety analysis. This requires efforts to identify and quantify the ranges and distributions of all relevant uncertainty contributors.

Paper S3.7: "Experience in KINS on best estimate calculation with uncertainty evaluations", presented by Young Seok Bang (KINS).

In order to support the licensing review by the Korea Institute of Nuclear Safety (KINS), regulatory auditing analysis for large break LOCA has been performed using the statistical KINS Realistic Evaluation Model (KINS-REM). They use the RELAP5/MOD3.3 and MARS-KS best estimate thermal-hydraulic codes. The method of the applicant is the KEPCO Realistic Evaluation Method (KREM). This statistical method was approved for the Westinghouse 3-loop cold leg injection plants large break LOCA in the year 2002. The method has been expanded, improved and approved to apply to various types of emergency core cooling (ECC) systems including Upper Plenum Injection (UPI), and Direct Vessel Injection (DVI). In both methods, the number of code runs is determined based on the non-parametric statistics and random sampling scheme. In the KINS-REM applications, conservative limiting values were used for some parameters, like peaking factor, containment pressure, safety injection water temperature and flow rates to keep conservatism instead of varying them, while other parameters were treated statistically. The KINS-REM will be applied now to evaluate important safety issues like fuel conductivity degradation with burn-up. The authors point out two other lines of improvement for the methodology: The reflood model of MARS code and the prediction of blowdown quenching.

Paper S3.8: "Coupled Code Analysis of the Rod Withdrawal at Power Accident including Uncertainty Evaluation Using CIAU-TN Method" presented by Tomislav Bajs (Enconet d.o.o.).

A Reactivity Initiated Accident (RIA) has been analyzed, i.e. a continuous uncontrolled Rod Cluster Control Assembly (RCCA) bank withdrawal at power. The power mismatch and resultant coolant temperature rise could eventually result in departure from nucleate boiling and/ or fuel melt. The influence of different coolant temperature measurement delays to related protection response and limiting system variables was investigated for various reactivity insertion rates. At first, a point kinetics model as implemented in RELAP5/MOD3.3 was used. The maximum insertion rate with rods in manual mode has been recalculated using the coupled codes RELAP5/PARCS. A COBRA model has been used to determine minimum DNBR for the hot channel. Preparation of cross section data were needed for the neutronics part of the coupled code. A modified CIAU method (named CIAU-TN) has been applied to evaluate the uncertainty of the coupled three-dimensional neutronics/ thermal-hydraulics calculations. Uncertainty matrices and vectors had to be filled like for the CIAU time and quantity uncertainty vectors. Two new driving quantities have been included in the definition of "status" of the plant: total reactivity and core average exposure. The objective is to provide automatically generated uncertainty bands for three output parameters: total power history, axial peaking factors distribution, and radial peaking factors distribution. That requires the development of specific tools in order to compare experimental or reference and calculated results to get accuracy values. However, full implementation and use of the procedure requires a database of errors not available at the moment, but the preliminary results give an idea of the errors expected to the problems of practical interest. Due to that, the discussed results are applicable only for a qualitative impression of impact of uncertainty.

Paper S3.9: "Uncertainty Analysis for LBLOCA of Wolsung Unit-I Reactor using MARS Code", Presented by Byoung Sub Han (ENESYS Co.).

An application of the statistical uncertainty method was presented for a large break LOCA in the CANDU-type reactor Wolsung Unit 1 in Korea. Wilks' method was applied, with 124 code runs performed using the MARS code, in order to obtain individual 95/95 upper tolerance limits for three outputs: peak fuel centerline temperature, peak cladding temperature and number of failed rods. Latin Hypercube

Sampling was used instead of simple random sampling, which is mostly used for ordered statistics. Uncertain inputs were assigned truncated normal or uniform distributions.

All the results of the 124 runs fulfilled the acceptance limits of temperature.

It was stated that good agreement was obtained with CATHENA results performed by the utility. Nearly the same results with those in the Final Safety Analysis Report were obtained. However, the important initial power peak after a large break LOCA due to a positive void coefficient was not calculated, but was imposed from another code result. 42 fuel bundle failures (95/95 upper tolerance limit) were calculated by MARS instead of 14 bundles calculated by CATHENA.

The study was supplemented by an importance analysis of the inputs, in terms of scatter diagrams of the two temperature outputs. Only two input parameters (fuel conductivity and break area) showed a clear correlation with the peak temperatures.

Ongoing work consists of introducing power and reactivity parameter uncertainty. Also, features of the safety system needs to be considered by MARS simulations.

3.3.2 Generic discussion from session 3

Uncertainty analysis is becoming common practice world-wide, mostly statistical method used. Uncertainty analysis is used for scenarios where safety parameters are getting close to regulatory acceptance criteria, like large cold leg break.

As for the BEPU methodologies based on nonparametric Wilks' method, an important concern is the Monte Carlo sample size. When the 95/95 upper tolerance limit approaches regulatory acceptance criteria, e.g. 1200°C PCT, the number of code runs may be increased to 124 or 200 calculations instead of the 59 obtained from Wilks' formula at the first order. This would be advisable for two reasons:

1) With increasing sample size the uncertainty results will be less dispersed, and consequently more converged (less conservative), and
2) The sensitivity results will be more reliable.

The USNRC Regulatory Guide 1.157 says that the applicable acceptance criteria will not be exceeded with a probability of 95% or more. If an additional confidence level is provided, the IAEA SSG-2 asks for at least 95%. Therefore, an overestimation of the 95% percentile with 95% confidence would be in line with requirements of these guides. An upper bound close to the theoretical 95% percentile is not required for licensing applications because the percentile may be higher than 95%.

As for the estimation of the output uncertainties, more important than the number of calculations are the high quality results of the base calculation, selection of uncertain input parameters, and the adequate assignment of probability distributions to input parameters.

The main lessons learned from all the exercises performed in the BEMUSE programme are also appropriate for the conclusions of this Workshop:

- A qualified user is needed to perform a high quality reference calculation, i.e. qualified nodalization, appropriate initial and boundary conditions, selections of code options; quality assurance procedures should be followed.

- A suitable code and uncertainty method should be used.

When applying the statistical method based on Wilks' theory, the following items are important:

- The identification and quantification of potential important uncertain input parameters is fundamental, i.e. phenomena, code models, initial and boundary conditions, material properties (e.g. fuel parameters). A proposed table should be made available with identified uncertain parameters, their ranges and probability distributions. This should be available for the scenario for which uncertainty analysis is mostly applied, like large break LOCA. It would also be beneficial for other break sizes and other events. A good example is the information available in the SNAP software tool for the TRACE code.

- More emphasis should be on methods for quantification of input uncertainties of code models using validation experience.

- The important input parameters that affect the course of the event should be clear to the user and the reviewer of an application.

- Simple random sampling (SRS) should be used to derive tolerance intervals or one-sided tolerance limits.

- The convergence towards the desired quantile (e.g. 95%), is increased by an increased number of code runs. The dispersion of tolerance limits is reduced by an increased number of code runs.

- The fulfillment of the regulatory acceptance criteria at a given tolerance level (e.g 95/95) is ensured when the corresponding tolerance limits meet such acceptance criteria. Generalizing this condition, the calculated tolerance regions must be under the regulatory limits. If the calculated tolerance limits approach the acceptance criteria, the number of code runs may be increased.

3.4 Technical Session 4. BEPU methods extension to new fields

The session addressed the extension of BEPU methods beyond their current use. By now such methods are mainly applied to classic deterministic environment but it is believed that their benefits could be extended to other fields. Seven papers were presented in the session dealing with subjects that fit in the objectives established in the workshop programme. The papers cover areas like: extension to CFD, quantification of global safety margins or the use of PSA

3.4.1 Summary of session 4 papers

This session comprised 7 papers.

<u>Paper S4.1: "Advanced approach to consider aleatory and epistemic uncertainties for integral accident simulations" presented by J. Peschke (GRS)</u>

The starting point of the paper is that safety analysis has to be able to account for both epistemic and aleatory uncertainties in a realistic manner when it is devoted to provide a well-founded risk-informed answer for decision-making.

An advanced probabilistic method, called MCDET (Monte Carlo Dynamic Event Tree), was presented. It had been developed at GRS to address this problem. The method allows for an integral simulation of complex dynamic processes. The presentation includes two application examples. The first application refers to a station black-out scenario. The other application is an analysis of the emergency operating procedure ‘Secondary Side Bleed and Feed’ which has to be applied after the loss of steam generator feed-water supply.

Despite of some questions about details of the presented results, it was acknowledged how the approach to integration of probabilistic and deterministic methods, as shown in the presentation, constitutes a candidate to verify in a comprehensive way the safety of a NPP. The current computing power as well as the optimization of schedulers and post-processing tools are making feasible the implementation of these methods.

Paper S4.2: **“**Safety Margin Assessment (SM2A): Stimulation for further development of BEPU approaches” presented by M. Zimmermann (PSI)

The paper deals with the combination of PSA and the analytical techniques developed in BEPU. Such combination has been carried out in the framework the CSNI/SM2A expert group.

An increase of the (conditional) probability of exceedance for a surrogate acceptance limit (PCT) indicating core damage was successfully evaluated for the selected sequences from several initiating event trees, and it was found that only a restricted number of sequences need to be analyzed.

This exercise exemplifies how the current BEPU methods can be tailored into PSA like safety verification process in order to give a detailed description of safety margin affectation following a plant modification.

A number of recommendations were drawn highlighting the need for further work. As an example: quantifying the exceedance frequency and sampling strategy, optimizing the computing effort, sequence delineation and validation.

Paper S4.3: “Combining insights from probabilistic and deterministic safety analyses in Option 4 from the IAEA Specific Safety Guide SSG-2”, M. Dusic (IAEA) et al.

Among the four options addressed by IAEA Specific Safety Guide SSG-2 on Deterministic Safety Analyses for Nuclear Power Plants (NPP), Option 4 is an attempt to combine insights from probabilistic safety analyses with deterministic approach. In Options 1 – 3 availability of safety systems is based on conservative assumptions whereas in Option 4 the availability of safety systems is derived using probabilistic arguments. The paper explains in more detail the approach proposed for Option 4, recognizing the fact that this option is still a research option and will remain so for some time. In the course of the following discussion and based on precedents shown in the presentation, it was pointed that the paper could be a starting point for a new standard for design basis accidents. It was also observed how, while preserving compatibility with basic safety principles, Option 4 represents the full exploitation of current knowledge on BEPU methods.

Paper S4.4: “Extension of BEPU methods to Sub-channel Thermal-Hydraulics and to Coupled Three-Dimensional Neutronics/Thermal-Hydraulics Codes” presented by K. Ivanov (PennState University).

The paper addresses the extension of BEPU methods to the sub-channel thermal-hydraulic codes on the example of the Pennsylvania State University (PSU) version of COBRA-TF (CTF). It also presents the application of Generalized Perturbation Theory (GPT) to generate uncertainties associated with the few-group assembly homogenized neutron cross-section data used as input in coupled reactor core calculations. This is followed by a discussion of uncertainty propagation methodologies, being implemented by PSU in cooperation of Technical University of Catalonia (UPC) for reactor core calculations and for comprehensive multi-physics simulations.

The paper exemplifies the tendency to integrate BEPU methods in a modeling platform, in this case neutronics and sub-channel analysis. It also describes possible approaches to deal with the propagation of uncertainties. In the course of the discussion it was mentioned the need to closely follow the insights that may arise from the PREMIUM project. It was also observed that the ongoing work on codes coupling and propagation of uncertainties will for sure help into the assessment of safety margins.

Paper S4.5: "Application of the Integrated Safety Assessment Methodology to Sequences with Loss of Component Cooling Water System" presented by C. Queral (UPM).

This paper describes a method integrating deterministic and probabilistic insights in the verification of safety of NPP. The method was applied to loss of component cooling water in the frame of CSNI/SM2A exercise.

The Integrated Safety Assessment (ISA) methodology, developed by the Consejo de Seguridad Nuclear (CSN), defines a so called damage domain (the region where the safety variable limit is exceeded) for each sequence of the dynamic event tree as a function of the operator actuations times, and the time of occurrence of stochastic phenomena. The exceedance frequency of the damage domain boundaries is then obtained. Reported results show a slight increment of the exceedance damage frequency for this kind of sequences in a power up-rate from 100% to 110%.

The focus of the following discussion was on the use of this sort of methods as a complementary means to design check, aiming at verifying the safety of the plant in terms of the delineation of the locus for the damage domain and corresponding frequency of exceedance with consideration to operator intervention, stochastic events and parametric uncertainties. It was also demonstrated the viability of this computer intensive approach through an appropriate management of the multitude of possible sequences.

The method was run making use of MAAP and TRACE codes together with the required modules from ISA software package.

Paper S4.6: "Uncertainty and sensitivity analyses for CFD codes: an attempt of a State of the Art on the basis of the CEA experience" presented by A. De Crécy (CEA)

This paper deals with the novel and challenging issue of uncertainty and sensitivity analyses, associated to the use of CFD codes as they are increasingly being used for fine 3-D modeling in connection with nuclear safety applications. It consists of two main parts. The first one is devoted to a description of the specificities of CFD codes for BEPU methods and focuses on the possible difficulties. Secondly the innovative research in this area at CEA is described.

Of special interest in this paper are the relevance of the so called categorical variables and the complexity of their specific treatment. As for the case of system codes, propagation of uncertainties and extrapolation of accuracy are suitable.

The paper describes in some detail the current activities within CEA on the subject and develops a couple of studies: a deterministic approach based on analysis of variance, and a probabilistic approach based on order statistics. The future work will make use of experimental data in order to check the uncertainty results. Also the mixed use of fine and coarse meshing will be explored.

In the subsequent discussion it was stressed the need to advance in the study of uncertainty and sensitivity studies in the field of CFD codes within the frame of NEA.

Paper S4.7: "Preliminary insights of the impact of steady state uncertainties on fuel rod response to an RIA" presented by C.López (Ciemat).

This paper addresses the influence of uncertainties in pre-transient rod characterization in thermo-mechanical analysis codes affecting the prediction of relevant variables during the fast transient modeling.

A RIA scenario of the CIP0-1 test (CABRI program) has been analyzed with FRAPCON-3 (steady state irradiation) and FRAPTRAN 1.4 (transient) codes. The input uncertainties in FRAPCON-3 have been propagated through the codes by following a deterministic approach (One-At-a-Time and Response Surface Method). It is noted the relevance of the uncertainties in the characterization assessment as they notably affect the accuracy in RIA modeling.

In the course of the discussion it is mentioned that this exploratory study will be extended to probabilistic methods. It is also pointed the importance to appropriately take into consideration the uncertainties in the characterization of initial conditions as they result from e.g. fuel operational history, and the careful and consistent propagation into the transient code.

3.4.2 Generic discussion from session 4

The session fulfilled the objective of establishing the general picture of the extension of BEPU methods beyond their current use. All the papers show preliminary applications of the presented methods and a first approach of the benefits expected. The applications demonstrate the feasibility of implementing BEPU methods in the different areas of safety analysis. Although in some of the presentations it is stressed the need for further research, it is also considered the importance of pilot applications in order to demonstrate the full potential of the different methods. The promotion of these activities should be further considered within NEA.

With regard papers related to the integration of probabilistic and deterministic methods, it was stressed the potential of using these methods to assess the safety of the NPP in a comprehensive way somehow filling the gap of probabilistic and deterministic approaches as standalone methods.

The acknowledgement and importance of extension of BEPU methods to other than system thermal-hydraulic codes was recognized.

4. SUMMARY AND RECOMMENDATIONS

The workshop managed to fulfil its general objectives. On the one hand a comprehensive state of the art of uncertainty analyses was presented and participants had the opportunity to carry out different discussions on the applicability and maturity of the developed methods. On the other hand actual applications were also presented as well as the extension of such methods to new fields.

The conference was an interesting opportunity to have a wide discussion of the whole "BEPU technical community". Such discussion pointed out participants' expectations for full-comprehensive exploitation of the BEPU methods.

From the contents of the technical material as well as the corresponding discussions, a number of recommendations can be extracted:

- Model uncertainties quantification was mentioned by different authors and also was the concern in different discussions. Such quantification was recognized as an activity worth of the current effort of the research community (CSNI/PREMIUM project).

1. *It is recommended to pursue in the efforts to achieve a consensus on the methods of quantification of input epistemic uncertainties and their treatment. PREMIUM project will contribute to solve this problem.*

- OECD projects from the past like UMS and BEMUSE along with the on-going ones UAM and PREMIUM were presented as a consistent movement leading to consecutive improvements in the consolidation of BEPU methods. Uncertainty related to multi-physics analyses (currently addressed in UAM and other NSC benchmarks) will require additional attention.

2. *It is recommended that future analytical or experimental activities include an evaluation of input & output uncertainties.*

- The feasibility of implementing BEPU methods in the different new areas of safety analysis was also presented. Participants emphasized the need of further research and pilot applications especially in these new areas as a way to advance in the future application in safety analysis.

3. *It is recommended to promote the extension of BEPU methods into other safety analysis areas like: fuel behavior, subchannel analysis, neutronics, and their coupling. NEA/NSC UAM project will provide relevant results on this subject. Pilot applications as a proof of concept should be favored.*

- A certain number of papers showed that powerful methods exist for plant safety verification purposes i.e.: comprehensive evaluation of global plant safety performance against postulated internal and external events. They advance into the integration of probabilistic and deterministic views in a consistent way. In view of the recent Fukushima accident, it is asserted that progress into integrated methods for safety verification is a need.

4. *It is recommended to promote the advance into the development of deterministic/probabilistic methods for safety verification purposes. The use of pilot applications should be considered in order to check the benefits and potentials of this approach.*

- The importance of validating BEPU methods and of reducing user effects was also an implicit conclusion of several presentations. Benchmarking exercises like BEMUSE have shown that large scatter among the different participants are present, casting doubts with regard the application of the method in licensing. Although BEPU methods have been used in increasing number for licensing, it was also observed that some of their aspects (especially evaluation of the safety margin) may present challenges to some regulators.

5. *It is recommended to pursue into the validation of BEPU methods in order to answer regulatory concerns.*

- It was observed that under the so called IAEA/SSG-2 Option 4, design basis analysis and design bases extension analyses can benefit from full application of BEPU methods together with credit to systems availability. At the moment this approach is in first steps and needs further development. A potential for a new design bases standard was acknowledged.

6. *It is recommended to advance into the development works and potential safety benefits outcome of BEPU methods application with consideration of systems availability (*option 4*)*

The recommendations of the workshop can be summarized by emphasizing that a great advance has been achieved since the beginning of BEPU activities, pointing to the consolidation of practices and nevertheless identifying still pending concerns. While the added value to safety with origin in the use of BEPU methods is recognized, the full potential of BEPU approach to a comprehensive safety assessment is still pending with regard to development. The CSNI and other international organizations like IAEA should play a leading role in this advancement.

APPENDIX I

CSNI Workshop on

OECD/CSNI Workshop on Best Estimate Methods and Uncertainty Evaluations

Hosted by
Technical University of Catalonia (UPC)
Spanish Nuclear Safety Council (CSN)

Barcelona, Spain, 16-18 November 2011

School of Industrial Engineering of Barcelona
ETSEIB, Av. Diagonal 647, 08028 Barcelona

Agenda

Wednesday, 16 November 2011

Opening session

8:30 Registration
9:30 Welcome and Introductory remarks, Professor Francesc Roure (UPC- ETSEIB Director), F. Pelayo (CSN) and F. Reventós (UPC)

Keynote papers
Chairman: F. Reventós

10:00 Paper K1 OECD BEPU programmes, A. Amri (OECD / NEA)
10:30 Paper K2 BEPU in safety guides, M. Dusic (IAEA)
11:00 Coffee break

TECHNICAL SESSION 1: Development achievements of BEPU methods and State of the Art
Chairman: T. Skorek (GRS)

11:30 Paper S1.1: “Summary of existing uncertainty methods”, H. Glaeser (GRS)

12:00 Paper S1.3: “Generic application of Wilks tolerance limit evaluation approach to nuclear safety”, In Seob Hong (KINS) et al.
12:30 Paper S1.4: **“**An Integrated Approach for Uncertainty Assessment and Characterization of Complex Best Estimate Safety Assessment”, M. Modarres (Maryland University)
13:00 Lunch break
14:30 Paper S1.2: “Information treatment in uncertainty analysis: some new developments towards the design of robust uncertainty analyses”, J. Baccou et al. (IRSN)
15:00 Paper S1.5: “Supporting database for uncertainty evaluation”, A. Petruzzi, et al (UNIPI)
15:30 Paper S1.6: “A procedure for characterizing the range of input uncertainty parameters by the use of FFTBM”, A. Kovtonyuk et al. (UNIPI)
16:00 Coffee break

TECHNICAL SESSION 2: International comparative activities.
Chairman: F. Pelayo

16:30 Paper S2.1: “The Findings from the OECD/NEA/CSNI UMS (Uncertainty Method Study)”, F. D’Auria (UNIPI) et al.
17:00 Paper S2.2: “Main Results of the OECD BEMUSE Progamme”, F. Reventós (UPC) et al.
17:30 Paper S2.3: “Discussion of OECD LWR Uncertainty Analysis in Modeling Benchmark”, K. Ivanov (The Pennsylvania State University) et al.
18:00 Paper S2.4: “PREMIUM- Benchmark on the quantification of the uncertainty of the physical models in the systems thermal-hydraulics codes”, T. Skorek (GRS)

Thursday, 17 November 2011

TECHNICAL SESSION 3: Applications: licensing, safety analysis support, regulatory body views and industry activities
Chairmen: H. Glaeser (GRS) / R. Mendizábal (CSN)

9:30 Paper S3.1: “Use and application of best estimate plus uncertainty methods. A regulatory view”, F. Pelayo, R. Mendizábal (CSN)
10:00 Paper S3.2: “Uncertainty Methods Development for the TRACE Thermal-Hydraulics Code by the U.S.NRC”, Stephen Bajorek (NRC)
10:30 Coffee break
11:00 Paper S3.3: “Westinghouse Experience in Licensing and Applying Best-Estimate LOCA Methodologies within the Industry: Past, Present and Future”, C. Frepoli (Westinghouse
11:30 Paper S3.4: “RELAP5/MOD3.2 Sensitivity Analysis Using OECD/NEA ROSA-2 Project 17% Cold Leg Intermediate-break LOCA Test Data”, T. Takeda (JAEA)
12:00 Paper S3.5: “Towards an industrial application of statistical uncertainty analysis method to multi-physical modeling and safety analyses”. Jinzhao Zhang (GDF Suez), et al.
12:30 Paper S3.6: “Utilization of Best Estimate System codes and Best Estimate Methods in Safety Analyses”, Jiri Macek (NRI)
13:00 Lunch break
15:00 Paper S3.7: “Experience in KINS on best estimate calculation with uncertainty evaluations”, Young Seok Bang (KINS), et al.
15:30 Paper S3.8: “Coupled Code Analysis of the Rod Withdrawal at Power Accident including Uncertainty Evaluation Using CIAU-TN Method”, Tomislav Bajs (Enconet d.o.o.) et al.

16:00 Coffee break

16:30 Paper S3.9: “Uncertainty Analysis for LBLOCA of Wolsung Unit-I Reactor using MARS Code”, Byoung Sub Han (ENESYS Co.) et al.

Friday, 18 November 2011

TECHNICAL SESSION 4: BEPU methods extension to new fields
Chairman: S. Bajorek (NRC)

8:30 Paper S4.1: “Advanced approach to consider aleatory and epistemic uncertainties for integral accident simulations”, Jörg Peshcke (GRS)
9:00 Paper S4.2: **“**Safety Margin Assessment (SM2A): Stimulation for further development of BEPU approaches”**,** M. Zimmermann (PSI)
9:30 Paper S4.3: “Combining insights from probabilistic and deterministic safety analyses in Option 4 from the IAEA Specific Safety Guide SSG-2”, M. Dusic (IAEA) et al.
10:00 Paper S4.4: “Extension of BEPU methods to Sub-channel Thermal-Hydraulics and to Coupled Three-Dimensional Neutronics/Thermal-Hydraulics Codes”, K. Ivanov (The Pennsylvania State University) et al.
10:30 Paper S4.5: “Application of the Integrated Safety Assessment Methodology to Sequences with Loss of Component Cooling Water System”, C. Queral (UPM) et al.
11:00 Coffee break
11:30 Paper S4.6: “Uncertainty and sensitivity analyses for CFD codes: an attempt of a State of the Art on the basis of the CEA experience”, A. De Crécy (CEA)
12:00 Paper S4.7: “Preliminary insights of the impact of steady state uncertainties on fuel rod response to an RIA”, Luís Herranz (Ciemat) et al.

Wrap up session & concluding remarks
Chairman: F.D’Auria (UNIPI)

12:30 Workshop summary and recommendations
13:30 Concluding remarks, Antoni Gurguí. Commissioner (CSN)
13:45 Closure cocktail

Reporting session (restricted to Chairmen and Organizing Committee)
Chairman: F. Reventós (UPC) / A. Amri (OECD / NEA)

15: 30 – 17:00 Material review. Proceedings preparation tasks