OECD-NEA expert group on multi-physics experimental data, benchmarks and validation

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OECD-NEA EXPERT GROUP ON MULTI-PHYSICS EXPERIMENTAL DATA, BENCHMARKS AND VALIDATION

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ABSTRACT

Coupled multi-physics computational methods continue to evolve to meet the needs of the R&D community designers, operators and safety regulators, in order to improve predictive accuracy and precision and to evaluate complex operational or accidental scenarios. Novel multi-physics simulation tools are designed to enable rigorous modelling of coupled behaviors between, *inter alia*, reactor physics, thermal-hydraulics, fuel performance and coolant chemistry. In order to be used to their full potential, these tools will require a more complex array of validation tests due to the multiple length and time scales, as well as the number of physical phenomena being simulated. However, the ability to conduct appropriate validation experiments has either progressed very little or in some cases significantly regressed. Recognition of this divide has led research and industry experts from across the NEA nuclear science community to form a new Expert Group on Multi-physics Experimental Data, Benchmarks and Validation (EGMPEBV)[*]. The paper describes the over-arching objectives of the group, in relation to the original motivations and eventual output goals. The specific tasks to be completed under the direction of the two established Task Forces are then presented alongside a depiction their inter-dependence.

Key Words: **multi-physics, benchmark, validation, experiment, modeling, simulation**

[*] www.oecd-nea.org/science/egmpebv/

1. INTRODUCTION

Computational analysis methods continue to evolve in many nuclear power countries to meet the needs of the R&D community, designers, operators and safety regulators, to improve predictive accuracy and precision and to evaluate complex operational or accidental scenarios that could have only been addressed by experimental means or simplified bounding calculations in the past. As a result of these developments, computational methods targeted at multi-physics and multi-scale simulations are beginning to be used both for deeper conventional analyses and for new applications. The goal of these codes is to allow modelling of highly complex scenarios at a very high level of spatial, phenomenological and/or temporal resolution and with demonstrated high accuracy. They also seek to enable rigorous modelling of coupled behaviours between, *inter alia*, reactor physics, thermal-hydraulics, fuel performance and coolant chemistry.

The increasing resolution of such analytical tools does not, however, eliminate the need for suitable validation via comparison to experiments. On the contrary, in order to be used to their full potential, these tools will likely require a more complete array of validation tests as a result of multiple length and time scales, as well as the number of physical phenomena being simulated. They will also require accurate measurements of all terms, including coupling terms, in situations where the appropriate experimental techniques and facilities might not exist today. However, the ability to conduct validation experiments has for some applications progressed at a slower pace than for computational methods, or in some cases it has significantly regressed (through shutdown of facilities, or through retirement of experts); furthermore, as modelling capabilities are reaching deeper levels in single areas and in coupled behaviours, appropriate experimental techniques simply do not yet exist. Recognition of this divide has led research and industry experts from across the NEA nuclear science community to form a new Expert Group on Multi-physics Experimental Data, Benchmarks and Validation (EGMPEBV). The aim of the group is to provide member countries with guidelines and recommendations for validating and improving their novel multi-physics simulations, and access to key experimental data.

2. MOTIVATION, OBJECTIVES AND GOALS

Validation of multiple physics models requires a wide variety of experimental data, which emphasises the importance of maximising the use of historically accumulated data to avoid the significant cost of performing similar experiments today. The preservation, evaluation and dissemination of such legacy validation data represent a cost-effective path forward to validate modern codes. Identification and prioritisation of key legacy data relevant to modern requirements is therefore one of the group’s primary goals. A review and evaluation of the data by experts, both current and contemporary to the experiments in question, will also be undertaken. The target end product will be evaluated and independently reviewed benchmark datasets with quantified uncertainties, which are of significantly greater value to users than the “raw” documentation. This will follow the process established by OECD-NEA in, for example, the ICSBEP and IRPhE projects. The EGMPEBV will also build upon efforts being made by other Expert Groups, such as the Expert Group on Uncertainty Analysis in Modelling (EGUAM), to develop methodologies and recommendations for uncertainty propagation.

One such set of experimental data is from the former Loss-of-Fluid Test (LOFT) facility in the United States where an NEA international project was conducted between 1983 and 1989[†]. LOFT data are particularly unique in that they originate from the only large-scale multiple-phenomena test facility that employed a nuclear powered core. Represented members from the United States have therefore made it a priority to collect, analyse and re-model these data so as to re-evaluate the uncertainties and the sensitivity of the measured data for use in multi-physics benchmarks. Support for this activity is being provided by the newly established U.S. Department of Energy's Nuclear Energy Knowledge and Validation Center (NEKVAC), which will work in close collaboration with the Expert Group and other similar national initiatives.

At the same time, while historical data are undoubtedly of great value, they may be limited by various factors; these usually relate to past experiments being targeted at the validation of older codes and the application of those codes. As a result, these historical data can often exhibit limitations including a lack of measurement accuracy or lack of knowledge of the measurement uncertainty in the experimental techniques; an absence of measurements of some critical parameters; and, an obscuring of relationships between individual physics phenomena owing to the output data resolution or simply the inability to allow for a detailed reinterpretation of the experiments based on the documented information.

Part of the role of the EGMPEBV will therefore be to help identify gaps in experimental data, where the scarcity of information is detrimental to the validation efforts of stakeholders. By comparing similar needs, efforts to fill such gaps may be co-ordinated across member countries. Where data does not exist, suitable experiments, facilities and measurement techniques may be proposed and developed to address those specific needs. A significant benefit of this international effort would be the leveraging of experimental capabilities that are likely to go beyond the capacity of any single country to implement to achieve the desired results – a true representation of cost efficiency for all partners involved.

Establishing consensus guidelines for the application of validation data is essential in light of the developing multi-physics code systems. The EGMPEBV will aim to establish standards for evaluating experimental data and determining how these data should be applied to the specific codes and applications in question. The resulting output, along with appropriate phenomena identification and ranking tables (PIRT), could help guide users on the applicability and importance of particular experimental data to reactor phenomena or scenarios of interest.

Finally, guidance for performing robust validation analyses is also important, including for methods to extrapolate uncertainties beyond the validation domain and for estimates of the degree to which stakeholders can rely on the results. This is closely related to the issue of scaling, or when factors must be applied to experimental results because of the extrapolation from the experimental configuration to a full-size application. To compile and make available such recommendations will thus be of significant benefit to the scientific community.

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† For more information on the LOFT Programme, see www.oecd-nea.org/jointproj/loft/

3. ORGANIZATION AND TASK FORCE ACTIVITES

The organization of the EGMPEBV relies on three Task Forces, focused on 1) Experimental Data, 2) Methods and Standards, and 3) Specific Applications (note however that the third Task Force is not yet fully constituted). The major aspects and expectations of Task Forces one and two are summarized below.

Task Force 1 is focused on experimental data qualification and benchmark evaluation. It aims at providing better and more accurate experimental datasets which support validation of high-fidelity multi-physics modelling and simulation (M&S) tools. At the same time it has to consider the incompleteness of past experimental data sets (in terms of data, documentation or uncertainties) and with the limited number of available multi-physics experimental facilities. Hence, the three main objectives of Task Force 1 are the following:

- reviewing and re-evaluating past experimental datasets for the validation of traditional or novel multi-physics codes,
- defining the needs and priorities for new experiments (e.g. pellet-clad interaction, cladding integrity, CRUD-Induced Power Shift and CRUD-Induced Localized Corrosion…), and
- establishing and recommending processes for designing new experiments using improved instrumentation, experimental techniques and data treatments with the intent to provide high quality data along with detailed uncertainty information, specifically acquired for validating high fidelity multi-physics M&S tools.

Task Force 2 was designed to develop validation methods and guidelines, and uncertainty qualification for the new family of multi-physics, multi-scale codes in the context of emerging demands such as longer fuel cycles and power uprate.

The capability to validate these codes has made significant progress. Modern validation, verification and uncertainty quantification (VVUQ) techniques enable analysts to extract information from existing experiments in a systematic manner and provide the users with a quantified uncertainty estimate. Currently, there are efforts in the U.S. (e.g. VERA within CASL [1], SHARP [2] and MAMMOTH [3] within NEAMS) and NURESAFE [4] in the EU to develop multi-physics/multi-scale analyses and associated validation techniques. These new approaches require evaluation of existing tests for appropriate data or to perform new tests to fill the gaps in required test data.

The principle objectives of Task Force 2 initiative are:

- development of consensus guidelines for validation of multi-physics M&S tools and data,
- development of guidelines for performing uncertainty qualification and evaluating ranges of applicability for predicting M&S performance outside of the validation domain, and
- identifying needs for specific experiments with the intended purpose of validating multi-physics M&S tools and data.

In the following sub-sections, each of the specific tasks planned under the two Task Forces, in order to meet the stated objectives, are described in detail. The links and inter-dependencies between these tasks are also depicted in Figure 1.

3.1 Task Force 1

3.1.1 Task 1: Define Scope of Multi-Physics Applications

The objective of this activity is to define the scope of the MPEBV activity as it relates to other activities within the OECD-NEA as well as to define the terminology that will be used to categorize the types of multi-physics benchmarks and simulation processes. Other Expert Groups under the auspices of the OECD-NEA focus on validation and benchmarking of single-phenomena physics (ICSBEP, IRPhE, etc.) or in some instances dual-phenomena physics (SINBAD, SFCOMPO, etc.). The intent of this Expert Group is on multi-physics M&S. As such, the Expert Group will establish the processes for engaging with the other Expert Groups (such as that on uncertainty analysis in modelling, EGUAM) and Task Forces under the auspices of the NEA. Furthermore, the Expert Group will engage with national validation centers and modeling and simulation development efforts (CASL, NURESAFE, etc.) within the NEA member countries.

Various groups utilize different nomenclature when describing multi-physics M&S as well as characterization of experimental data and types. However, the semantics employed to describe these areas differ among those focused on nuclear safety as compared to those focused on the nuclear science areas. In order to provide some consistency and coordination among these focus areas, the EGMPEBV activity would classify the experimental datasets into three separate areas:

- separate effect tests (SET),
- multiple effect tests (MET),
- plant measurements and observations (PMO).

The choice of these designations is to provide consistency with existing nomenclature employed by much of the nuclear community as well as to minimize confusion when differences exists between those in the nuclear safety fields and those in the nuclear science fields. This task will also provide concise and clear definition on the differences between novel (N) and traditional (T) methods, what is meant by “coupling”, how uncertainty methods have been used for sensitivity and uncertainty analyses, etc., a description and definition of the scope of traditional (T) multi-physics applications will be developed along with a description and definition of the scope of novel (N) multi-physics applications.

3.1.2 Task 2: Summary Reports on the Current Status and Expected Needs for Validation of Multi-Physics Modeling and Simulation Tools

One of the objectives of this task is to develop a report that summarizes the use of best estimate plus uncertainty (BEPU) evaluations in industry and regulation based on traditional (T) multi-physics calculations supplemented by sensitivity analysis (uncertainty quantification (UQ)). To reduce excessive conservatism associated with the design of some operational and safety systems, industry representatives and regulators have started using best-estimate analyses coupled with probabilistic risk assessment to evaluate plant operation under normal and off-normal conditions in lieu of the use of worst case scenario approaches. The move toward best-estimate analyses (and thus toward enhanced uncertainties analysis) in lieu of bounding analyses has resulted in the need to better model the physical phenomena in nuclear reactors. This report will summarize the approaches for benchmarking and validation of traditional multi-physics modeling and simulation tools.

A second objective of this task is to develop a report that will summarize the current approaches to migrate from traditional (best-estimate plus uncertainties – T/BEPU) to novel (high-fidelity first principles with embedded uncertainty quantification – N/UQ) multi-physics modeling and simulations. This report will include a summary of the activities in countries or multi-national approaches such as CASL, SHARP, MAMMOTH, NURESAFE etc. for validation of specific problems.

The final objective of this task is to develop a summary report on the availability of experimental data that will be needed to validate both traditional and novel modeling and simulation (M&S) codes. This report should describe the following:

a. Available reactor physics data and benchmarks;
b. Available fuel modeling data and benchmarks;
c. Available core thermal-hydraulics data and benchmarks;
d. Available system thermal-hydraulics data and benchmarks;
e. Available traditional (T) multi-physics data and benchmarks; and
f. Anticipated needs for validation of traditional (T) and novel (N) multi-physics tools.

3.1.3 Task 3: Summary Report on the Major Challenges and Priorities for Validation of Multi-Physics Modeling and Simulation Tools

Some of the key issues facing the nuclear industry include the aging of the nuclear fleets throughout the world, the need to extract more from the nuclear fuel with higher burn-up, the desire to increase the power output of existing reactors, the need to develop alternate accident-tolerant fuels, and the need for better understanding of normal and off-normal operating conditions, to name just a few. Several operational challenges for nuclear power plants such as crud-induced power shifts, crud-induced localized corrosion, pellet-cladding interactions, and grid-to-rod fretting cannot be adequately addressed using conventional M&S tools and analyses; hence, conservative estimates of the impacts of these phenomena on reactor operations are often assumed to ensure the safe operation of nuclear power plants. In addition, significant safety issues such as departure from nucleate boiling, loss of coolant accidents and reactivity initiated accidents are often analyzed using rather conservative estimates of the likelihood of such events as an added precaution. Such excess conservatism may lead to less than optimal operation of the plants.

This task will produce a report that addresses the uncertainty treatments in the validation process for these challenge problems and the potential benefits to reducing the excess conservatism. What is the impact of best estimates as compared to high fidelity simulations as compared to other as yet to be defined approaches? The report should address the views of both the vendor/operator that desires to make the optimal use of a plant/facility as compared to the desire of a regulator to ensure the safety of the plant/facility (performance vs. safety). This report should also address the differences in the challenges/problems that might arise when considering different reactor design (Gen. II&III, Gen. IV, etc.). The EGMPEBV focus is on currently operated Light Water Reactors (LWRs) from Generation II, next to be built Generation III and Generation III+ LWRs as well as Small Modular Reactors (SMRs) and potentially representatives of Generation IV – High Temperature Reactors (HTRs) and Fast Reactors (FRs).

The part of the report discussing the challenges and priorities for validation of traditional (T) multi-physics modeling and simulation tools will address:

a. Using the existing data;
b. Creating new data – priorities and mechanisms;
c. Including uncertainty quantification in traditional (T) multi-physics simulations (BEPU methodologies) and validation of uncertainty quantification methods: status, needs and priorities.

The experience and expertise in uncertainty propagation in traditional (T) multi-physics calculations and applications of BEPU methodologies will be summarized including experiences by countries as well as large international projects such as the OECD-NEA LWR Uncertainty Analysis in Modeling (UAM) and International Atomic Energy Agency (IAEA) HTR UAM Coordinated Research Program (CRP).

3.1.4 Task 4: Recommendations and Implementation of Processes for Evaluating Existing Experimental Data for Multi-Physics Modeling and Simulation

The objective of this activity is to define and implement the processes for evaluating past experimental data sets and validation efforts including the quantification of uncertainty in experimental data, the ranking of important physical phenomena, the identification of important measured parameters, the processes for converting raw experimental data to measured parameters, the processes for converting the measured parameters to modeled parameters if they differ, etc. Furthermore, guidance will need to be provided on the level of acceptability of uncertainty data for those experiments that are to be considered benchmark quality and those experiments that will only be considered for general purpose testing. Special attention has also to be given to the completeness and the representativeness of existing experimental data sets.

Consideration will be given to the conversion of "measured" parameters to parameters that can be directly simulated using multi-physics methods. The analysis should include the conversion of the "raw" data to the "measured" data. This should also include the treatment of uncertainties from the conversion process and also any uncertainties from the approximation methods employed in the simulations. Focus will be given to the existing data with uncertainties from nuclear power plants operation and tests i.e. plant measurements and observations (PMO). The implementation of this activity will result in evaluations of experimental data provided by participants form the various member countries. This activity is closely related to task 7 that involves the development of the benchmark models from the evaluated experiments. This will entail establishing a peer review process and database systems for collection and retention of the evaluated experiments. The resulting evaluations and databases will be shared among all member countries of the Expert Group.

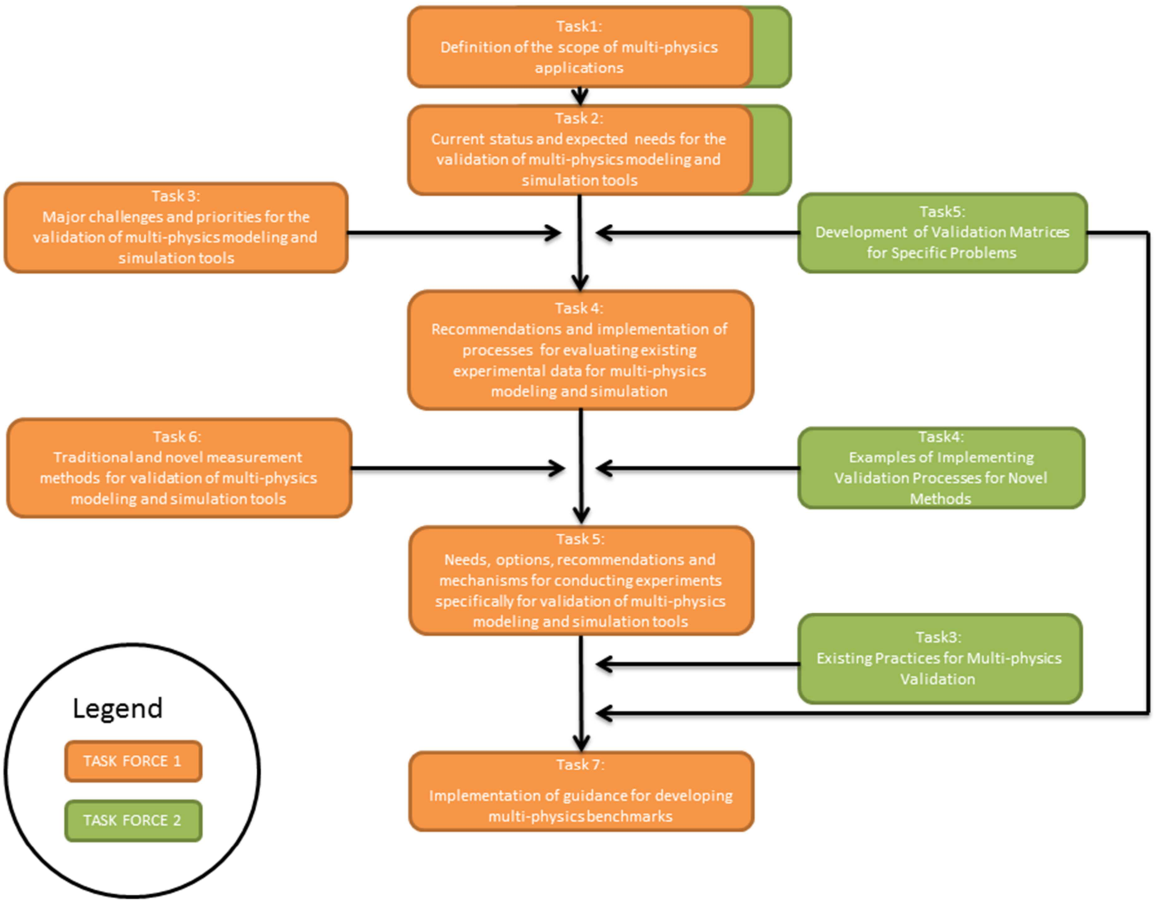

Figure 1. Organization and dependencies between activities of the two Task Forces.

3.1.5 Task 5: Needs, Options, Recommendations and Mechanisms for Conducting Experiments Specifically for Validation of Multi-Physics Modeling and Simulation Tools

The availability of new facilities for conducting multi-physics experiments is of a concern. No country among the NEA membership maintains or operates a full complement of facilities that would be needed to study and evaluate all of the possible multi-physics phenomena and the coupling of these phenomena. The cost for such facilities often exceeds that which could be borne by a single country. As such, collaborative arrangements need to be considered for optimal use of limited resources among the NEA member countries.

The need to have access to prototypical experimental conditions with a complete and good quality experimental dataset (hence a complete and adapted set of instrumentations and experimental techniques) should also be addressed. A key outcome of this task will be to review and update the NEA report on “The Research and Test Facilities Required in Nuclear Science and Technology”. This updated review should include a comprehensive review of the experimental facilities in Russia because of the breadth of facilities and capabilities that have not before been catalogued by the NEA. This report should address the challenges with proprietary data sharing and how this could limit the validation of multi-physics M&S tools and data.

The report will address also what data needs to be collected from nuclear power plants, especially from the new plants during their commissioning tests and subsequent operation. The new plants have better measurement capabilities, as demonstrated by the OECD VVER-1000 Kalinin-3 Coupled Code Benchmark, where high-quality multi-physics data was collected during a commission test at the start-up of Kalinin-3 unit, and subsequently used to develop an international benchmark. Similar opportunities exist with the commissioning of AP1000, EPR-1600 and other new plants worldwide. A report will also be generated to identify the high-priority needs for the broader nuclear industry. A critical activity of this group will be to identify mechanisms to foster international collaboration in fulfilling the needs for those high-priority experiments identified in the summary report, including a recommendation for an initial demonstration of such a collaborative effort.

3.1.6 Task 6: Summary Report on Traditional and Novel Measurement Methods for Validation of Multi-Physics Modeling and Simulation Tools

The objective of this activity is to develop a report on traditional measurement methods and the limitations of those methods that could be improved to be more representative of the parameters that can be simulated. Identify "ideal" improvements for some measurements that would provide more fundamental parameters for direct comparison with simulations. There is also a need to address the evolution of measurement methods using modern tools as compared to those used in past experimental facilities (novel vs. traditional measurement methods).

3.1.7 Task 7: Summary Report and Implementation of the Guidance for Developing Multi-Physics Benchmarks

The objective of this activity is to define the process and methodologies for evaluating, documenting, and utilizing multi-physics benchmarks. This effort will build from the experience of the NEA in the development of the ICSBEP and IRPhE benchmarks as well as the traditional (T) multi-physics benchmarks using experimental data such as OECD Ringhals BWR Stability benchmark, OECD/NRC BWR TT benchmarks, OECD/DOE/CEA V1000 CT benchmark, OECD Kalinin-3 Coupled Code benchmark, OECD/NRC Oskarshamn-2 BWR Stability benchmark and the OECD LWR UAM benchmarks. The established procedures within OECD-NEA for developing benchmarks for traditional (T) multi-physics tools will be summarized. The guidance, developed by Task Force 2, will include the requirements and processes for describing and documenting the physical characteristics of multi-physics benchmarks, the requirements for quantifying uncertainties in the physical characteristics and the measured parameters, the processes for equating the actual measured parameters and their associated uncertainties to modeled parameters, etc. The implementation of the guidance will result in benchmark evaluations that will be archived and distributed to all member country participants in the Expert Group.

3.2 Task Force 2

3.1.1 Task 3: Summary Report on the Existing Practices for Multi-physics Validation

Code developers, research organizations, and professional societies have developed various practices for validation of M&S tools and data. The approaches may vary depending on the limitations of the M&S tools and data as well as the intended application of such M&S tools. A report will be developed that summarizes some of the primary practices, including recommendations and guidelines that have been developed within the member countries of the NEA. Some of the key factors that will be included in the summary report are as follows:

1. Review and selection of an assessment frameworks such as the following:
   a. Code Scaling Applicability and Uncertainty (CSAU)
   b. Predictive Capability Maturity Modeling (PCMM)
   c. Enhanced PCMM
   d. Quantification of Margins and Uncertainties (QMU)
2. Utilization of Phenomena Identification and Ranking Table (PIRT)
   a. Use of sensitivity and uncertainty analyses
   b. Use of expert opinion
   c. Use of non-dimensional parameters: benefits, cautions, and consequences
   d. Weak versus strong coupling
3. Use of the validation hierarchy; see for example the ‘pyramid’ representation in Figure 2.
   a. Coupling of physical phenomena (ad-hoc vs. first principles)
   b. Coupling phenomena with varying degrees of fidelity: temporal, spatial, and energy
   c. Integration of the levels of the validation hierarchy with uncertainty propagation
4. Evaluation of experimental uncertainty
   a. Direct (e.g. measured flow rate) versus indirect (imaging of bubble formation in turbulent flow) experimental observations
   b. Propagation of error from “measured” data that is inferred from experimental observations from instruments (e.g. uncertainties in electronic signals from thermocouples or radiation detectors into “measured” quantities of interest)
5. Segregation of calibration data from validation data
6. Extrapolation beyond the validation domain
   a. Estimating the uncertainty in model input data for the application of interest
   b. Estimating model form uncertainty at the application of interest
   c. Identifying and distinguishing aleatory and epistemic uncertainty

The summary report will identify several commonly used assessment frameworks and summarize the general approach, the strengths, the weaknesses and ease of use of these frameworks. The report will also include an overview of the PIRT process along with the key issues that must be considered when identifying relevant physical phenomena and the coupling among the phenomena such as thermal-hydraulics and neutronics. The report may include a summary of the principle issues to consider when coupling physical phenomena that have varying degrees of fidelity in the temporal, spatial and/or energy domains. Likewise, the report will summarize current approaches for estimating total uncertainty at various levels of the validation hierarchy and the cautions and challenges in such estimates. The report will also provide recommendations as to the treatment of experimental uncertainty and the inference of measured data with respect to simulated responses of interest. In some instances, the underlying physical phenomena are approximated in the simulations and engineering approximations may be used to model observed behavior using rudimentary models that rely on "calibrations." The report will include recommendations for the use of "calibration" and the propagation of uncertainty from this use. A critical topic in estimating the total uncertainty at the application conditions of interest is how to estimate the model form uncertainty using validation metrics. Finally, the report will include a summary of the primary recommendations for the use of multi-physics modeling and simulation tools extrapolated beyond the validation domain.

3.2.2 Task 4: Examples of Implementing Validation Processes for Novel Methods

The objective of this task is to develop a summary report on the current progress of individual member countries or multi-national organizations in the application of validation approaches for specific problems. Member countries will be encouraged to annually submit reports to the Task Force that describe the validation of advanced M&S tools and the approaches employed therein. The CASL program in the U.S. and the NURESAFE program in the European Union have already made significant progress in validating advanced M&S tools for specific problems, which will be compiled by the Task Force in an annually updated report.

3.2.3 Task 5: Development of Validation Matrices for Specific Problems

The nuclear industry is required to provide sufficient evidence regarding the predictability of reactor behavior under certain situations and scenarios. The analysis of these off-normal events often entails the use and validation of M&S tools to ascertain the degree of certainty regarding the predictability of a reactor under such off-normal conditions. Furthermore, the nuclear industry has identified a few specific "challenge" problems in which the use of advanced M&S tools and data could be used to reduce excess conservatism or improve predictability of safety concerns. These challenge problems are likely to be dependent on the reactor type and operational constraints. As such, the Task Force will undertake to develop validation matrices for "standardized" scenarios and challenge problems such as, for example, departure from nucleate boiling, crud induced power shifts, fuel-cladding and cladding-coolant interactions. Member countries will be asked to identify specific standardized scenarios or challenge problems and then to develop a validation matrix for the specific problem by identifying the validation data for the various physical phenomena and at different levels of the validation hierarchy. The Task Force will define a standardized format for the validation matrix and thereafter annually compile the member country contributions into a summary report to be submitted to the NEA.

The development of the validation matrices will serve as the starting point for identifying gaps in the validation data sets and or identifying the availability of data sets that could be shared among member countries. The Task Force will review the member country contributions provided under task 5 and identify gaps in validation data for the same problem. Additionally, the comparison among the member country submissions for the same problem could serve to identify data sets that might be shared among the member countries. Following each update, the Task Force will develop a summary report that identifies gaps in the validation matrices for specific problems. If appropriate, the Task Force may provide recommendations for new experiments or for the sharing of existing experimental data.

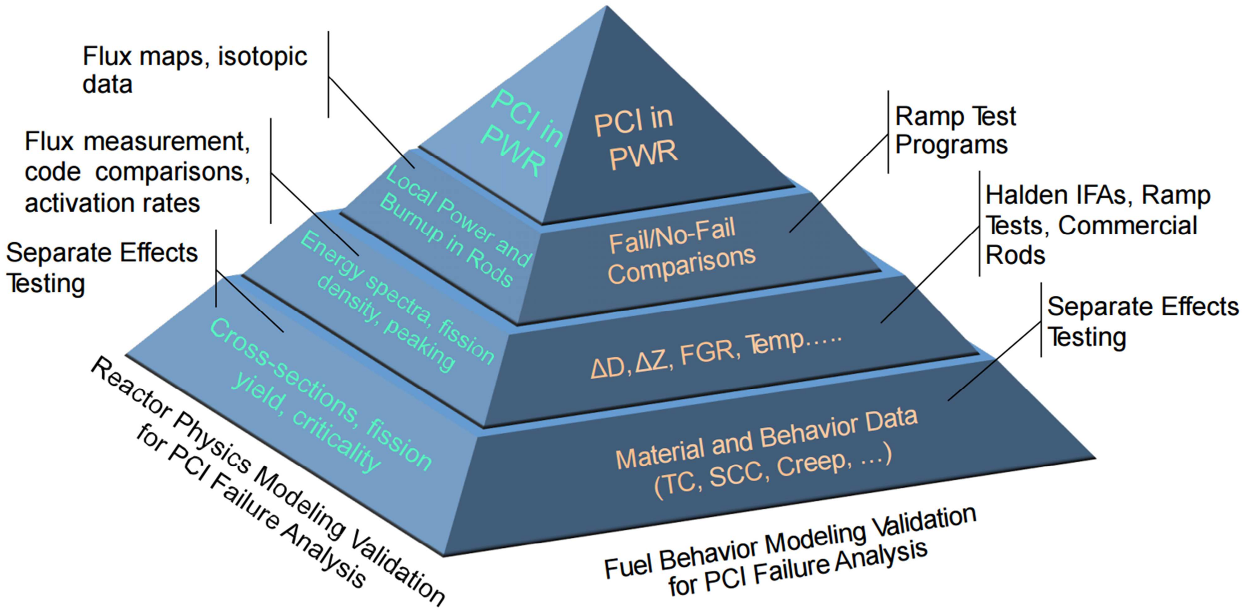

Figure 2. Example validation pyramid for the important physical phenomena in pellet-clad interaction (PCI) simulation.

4. CONCLUSIONS

It is clear that the planned objectives of the EGMPEBV are extremely challenging and will require significant effort to achieve. However, the participants have already committed to a demanding schedule of work and have achieved good progress on a number of the initial tasks. Furthermore, additional contributors to the group are still being sought in order to provide the diverse expertise necessary to achieve the scope of objectives described. Despite the breadth of the task at-hand, the ultimate aim is clearly understood by the members, which is for the nuclear industry to be able to realize the potential benefits of novel methods over traditional ones.

Finally, it is noteworthy that a third Task Force is currently under formation to address specific applications of multi-physics methods, through application of the outcomes of the first two Task Forces. Its intention will be to concentrate on novel high accuracy start-up measurements from Russian VVERs, and potentially also the challenges presented by new, or newly restarted, fuel transient testing reactors.

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