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ON THE ROLE OF VALIDATED SIMULATIONS WITHIN THE EUROPEAN NUCLEAR FISSION TECHNOLOGY PLATFORM

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ABSTRACT

This paper highlights the role of validated simulation code systems within the ongoing EURATOM Coordination Action "Sustainable Nuclear Fission Technology Platform" (SNF-TP). The SNF-TP proposes research structures and programs for developing a coherent European strategy for: (i) improving the performance of currently operating (Generation II) and future near-term (Generation III and III+) Light Water Reactors (LWR) while maintaining a high degree of safety, performing studies regarding the feasibility of novel designs, and establishing a unified approach of LWR life time extension; (ii) establishing a sustainable, closed fuel cycle for electricity production using innovative (Generation IV) fast neutron reactor systems in conjunction with partitioning and transmutation (P&T) technologies; (iii) establishing a commercially viable High Temperature Reactor (V/HTR) for process heat and hydrogen production; (iv) assuring adequate training to preserve and enhance the human competence in the nuclear field, and maintaining/renewing the infrastructure necessary for achieving sustainability of nuclear energy; and (v) implementing a Strategic Research Agenda for conceiving and coordinating the European research and development in nuclear science and technology.

Numerical simulations and validation activities comprise transversal activities common to all types of reactors as well as issues which are specific for each type of reactor system. Besides performing specific experiments and developing specific simulation models, essential activities are "code verification" ("is the code solving the mathematical model correctly?"), "code validation" ("does the model represent reality?"), and "code qualification" (certifying that a proposed simulation/design methodology/system satisfies all performance and safety specifications). Code validation and qualification (V&Q) can be attained only by selected benchmarking, taking into account systematically (i.e., using sensitivities) all sources of uncertainties (computational, experimental, etc.). The development of software modules for validation and verification of simulation programs, including global sensitivity and uncertainty analysis, is a generic issue of fundamental importance for the safe operation of all types of reactors while reducing uncertainty design margins. The scope of this paper is to sketch briefly the role of validated simulations in the context of the (above mentioned) strategic elements of the EURATOM Coordination Action SNF-TP.

Key Words: Code Validation, Sensitivity and Uncertainty Analysis, Nuclear Technology Platform

1. INTRODUCTION

Current forecasts indicate that the primary energy consumption in 2050 will at least double by comparison to the year 2000. This increase is driven by the demographic growth, accelerated industrialization of certain geographical zones, and the general aspiration of people towards a standard of living comparable to the currently advanced countries. Energy security is a major global concern, all while developing carbon-free, or low-carbon, energy technologies. Considering the combined effects of (i) the probable increase in the price of fossil (oil, coal, and gas) energy sources (due to their limited availability) and (ii) the adverse climatic effects caused by the massive emission of greenhouse gases and other pollutants from fossil energy sources, a globally coherent energy strategy is needed to address energy supply and demand, taking into account the complete life-cycle of the various energy sources, including the production, transmission, and distribution of energy, energy conversion, impact on energy equipment manufacturers, on end-users, and on the environment. Taking into account all of these (sometime conflicting) factors, it is likely that renewable energy sources will be developed preferentially together with nuclear energy.

Nuclear energy yields 35% of the electricity produced in the European Union, and is a key element for reducing greenhouse gas emissions, reducing the growing energy dependency of the European Union on unreliable imports, and optimizing the internal market on fossil energy sources. On 8 March 2006, as a response to a request of the UK presidency in November 2005, the European Commission published a new *Green Paper on Energy*: "*A European Strategy for Sustainable, Competitive and Secure Energy*" [http://europa.eu.int/comm/energy/green-paper-energy/index_en.htm, COM (2006) 105]. A major objective is to achieve 50 % of energy production from secure, low-carbon sources within 20 years. The energy mix policy of the EU takes all primary energy sources (fossil, renewables, and nuclear) into consideration, as are also all energy carriers (systems or substances used to transfer energy from somewhere to somewhere else, e.g., electricity, hydrocarbons and hydrogen).

To ensure the viability of the needed mix of energy sources in Europe, the European Commission has supported the creation of several "Energy Technology Platforms", covering the most strategic fields of energy-related technology. In particular, the key strategic elements for achieving the vision of sustainable nuclear energy are: (i) a concerted effort, with continuity and full support of all stakeholders; (ii) focus on key technological advancements; and (iii) a comprehensive and structured research agenda. For this purpose, twenty two European research, academic, and industrial organizations are currently cooperating on a EURATOM project entitled "Sustainable Nuclear Fission Technology Platform [1]" (SNF-TP), planning research structures and programs for developing a coherent European nuclear strategy for:

- **A.** Improving the performance of currently operating (Generation II) and future near-term (Generation III and III+) Light Water Reactors (LWR) while maintaining a high degree of safety, performing studies regarding the feasibility of novel designs such as the Supercritical Water Reactor (SCWR), and establishing a unified approach of LWR life time extension;
- **B.** Establishing a sustainable, closed fuel cycle using innovative (Generation IV) fast neutron reactor systems for electricity production;

C. Establishing a commercially viable Very High Temperature Reactor (VHTR) for process heat and hydrogen production;

D. Assuring adequate training to preserve and enhance the human competence in the nuclear field, and maintaining/renewing the infrastructure necessary for achieving sustainability of nuclear energy. Cooperation with other EU-Projects, especially the hydrogen platform, geological waste disposal, and fusion materials activities.

Numerical simulations and validation activities comprise transversal activities common to all types of reactors as well as issues which are specific for each type of reactor system. Besides performing specific experiments and developing specific simulation models, essential activities are "code verification" ("is the code solving the mathematical model correctly?"), "code validation" ("does the model represent reality?"), and "code qualification" (certifying that a proposed simulation/design methodology/system satisfies all performance and safety specifications). Code validation and qualification (V&Q) can be attained only by selected benchmarking, taking into account systematically (i.e., using sensitivities) all sources of uncertainties (computational, experimental, etc.). The development of software modules for validation and verification of simulation programs, including global sensitivity and uncertainty analysis, is a generic issue of fundamental importance for the safe operation of all types of reactors while reducing uncertainty design margins. The scope of this paper is to sketch briefly the role of validated simulations in the context of the (above mentioned) strategic elements of the EURATOM Coordination Action SNF-TP.

2. A EUROPEAN VISION FOR SUSTAINABLE DEVELOPMENT OF NUCLEAR FISSION TECHNOLOGY

To attain sustainability, nuclear fission energy must overcome several important challenges, which extend over three time horizons: today, 2010 and 2040. Each of these time-horizons is associated with a corresponding generation of nuclear power technologies, as follows:

- Generation II (today); challenges: security of supply and environmental compatibility;
- Generation III (around 2010); challenges: enhanced competitiveness (economics), and enhanced safety and reliability;
- Generation IV (around 2040); challenges: cogeneration of heat and power, with a sustainable closed fuel cycle.

The cornerstones of the envisaged strategy for attaining sustainable development of nuclear energy are briefly presented in the following sections.

2.1. Generation-II and Generation-III Light Water Reactors (LWR)

Although LWRs of Generation-III are already being deployed in Europe, Generation-II LWRs continue to produce the bulk of nuclear electricity, a situation that is expected to remain at least until 2035. It is therefore important to extend the life of Gen.-II LWRs while maintaining a high degree of safety in their operation, and improving their performance. For both Gen.-II and III LWRs, innovative research continues to play a major role for improving (i) probability safety analysis (PSA) methods: (ii) life time management; (iii) passive safety features; (iv) mitigation of severe accidents; (v) fuel performance; (vi) Pu-conversion capabilities, to reduce uranium consumption, thus increasing the flexibility of the fuel cycle; (vii) optimization of economic performance; (viii) standardized simulation tools based on multi-scale and multi-physics capabilities for reducing uncertainties and improving operation margins. Further research is needed to evaluate the deployment of Generation-III technologies, including evaluation of reactor performance and safe operation. Research is also needed to address the socio-economic and public perception issues of near-term deployment. Additional efforts are needed to establish a link with other EU initiatives on understanding planning consent, financing models as well as market mechanisms (CO_2 taxes, obligations etc) for encouraging the deployment of low carbon technologies. Research on novel LWR designs and assessment of the feasibility of the Super-critical Water Reactor (SCWR) should also continue. Last but not least, it would important to establish a unified approach to life extension of currently operating LWRs.

2.2. Generation-IV Nuclear Systems with Sustainable Closed Fuel Cycles

Among the fast reactor systems, the technological basis for the Sodium-cooled Fast Reactor (SFR) is currently the most comprehensive, based on experience gained internationally from operating research, demonstration and commercial-size reactors. The technological basis gained from these reactors includes key elements of the overall reactor design (pool- or loop-type), large-core design, fuel types (metal, carbide, nitride, oxide), safety, and fuel cycling. The main issues to be addressed in order to reduce the costs and improve the safety of SFRs include: design simplification (e.g., suppression of the intermediate sodium circuit, replacement of the water-cycle by innovative high-efficiency cycles), improvement of in-service inspection and repair, mitigation of the hypothetical re-criticality severe accident, use of innovative fuel allowing grouped-actinide separation for minimizing the high-level waste production and enhancing proliferation resistance within a closed-fuel cycle. None of these remaining issues appear unsolvable, so that the SFR is currently considered as a promising fast reactor system for achieving sustainability of nuclear energy production in the medium term.
While the SFR is the reference technology, two alternative technologies for fast reactors, namely the Gas-cooled Fast Reactor (GFR) and the Lead-cooled Fast Reactor (LFR) are also under consideration within the SNF-TP. The GFR has the potential of reaching higher operating temperatures and efficiency, thus opening the way towards further industrial applications. Advantages of the GFR include its neutronic- and optical-transparency, as well as chemical inertness of helium coolant. However, the GFR technology is considerably less developed than the SFR technology. The most important technological challenges to be resolved include the development of self-sustainable cores using innovative fuel, safety and system development for managing the decay heat removal under accident conditions, and establishing a sustainable fuel cycle. Innovations are needed for developing GFR fuel and structural materials resistant both to fast neutrons and high temperatures.

The LFR has a large thermal inertia due to the heavy liquid metal, and its non-reactivity with air and water could allow an integrated design with the heat exchanger inside the reactor vessel. Furthermore, lead is inexpensive and can operate at low pressure and low pressure losses. However, the LFR technology is less developed than the SFR technology; in particular, the corrosion/erosion phenomena at high speeds and temperatures, and the choice of a suitable fuel cladding material have not been sufficiently established. Other issues to be addressed for the

LFR system are similar to the ones to be addressed for the SFR, namely: improvement of in-service inspection and repair, use of innovative fuel allowing grouped-actinide separation for minimizing the high-level waste production and enhancing non-proliferation within a closed-fuel cycle, etc.

In parallel with the development of a robust fast reactor system, a flexible separation and treatment strategy needs to be assessed, aiming at a closed fuel cycle that includes the recycling of actinides, consistent with the optimization of the front- and back-ends of the fuel cycle. Important milestones in this strategy include the demonstration of the grouped actinides extraction process on a laboratory scale during 2008-2015, the development of transuranium (TRU) transmutation fuels for implementing actinides extraction, accompanied by reactor irradiation of TRU fuel. Such a long-term, coherent strategy would permit the transition from the currently practiced mono-recycling of plutonium in Light Water Reactors (LWR) to the recycling of actinides (U, Pu, MA) in Generation IV-reactors, thereby allowing minimization of radiotoxicity in the ultimate waste. Accelerator Driven Systems (ADS) may also be considered for transmutation purposes, but only if their technological and economical feasibility is conclusively demonstrated.

2.3. Very/High Temperature Reactor (V/HTR)

A nuclear reactor capable of producing both electricity and high-temperature heat would open additional industrial applications, including the possibility of producing very efficiently industrial quantities of hydrogen (based on the high temperature electrolysis or thermo-chemical decomposition of water) and/or bio-fuels. Such a reactor system would be based on a Helium-cooled core with a thermal neutron spectrum, and would use a combined Brayton and Rankine cycle. However, such a reactor system would not be self-sustainable by itself, and the treatment process for the spent fuel from a VHTR still remains to be developed.

2.4. Transversal Activities: Simulations and Experiments, Education, Training and Infrastructures

Numerical simulations and validation activities comprise transversal activities common to all types of reactors as well as issues which are specific for each type of reactor system. Besides performing specific experiments and developing specific simulation models, essential activities are “code verification” (“is the code solving the mathematical model correctly?”), “code validation” (“does the model represent reality?”), and “code qualification” (certifying that a proposed simulation/design methodology/system satisfies all performance and safety specifications). Code validation and qualification (V&Q) can be attained only by selected benchmarking, taking into account systematically (i.e., using sensitivities) all sources of uncertainties (computational, experimental, etc.). The development of software modules for validation and verification of simulation programs, including global sensitivity and uncertainty analysis, is a generic issue of fundamental importance for the safe operation of all types of reactors while reducing uncertainty design margins.

Keeping available human competences in nuclear science and engineering has been identified by the EU as most pressing concern for the coming decades. For example, in its report "Nuclear competence building, summary report, OECD 2004, NEA n°5588", the OECD/NEA confirmed that "In most countries, nuclear education had declined to the point that expertise and competences in core nuclear technologies were becoming increasingly difficult to sustain". The lack of qualified human resources will affect the R&D and management capabilities of research institutions, industry and utilities: the OECD/NEA reports note that "within companies, R&D is as important for training staff as for technical advancement". The EURATOM E&T activities in nuclear engineering, radioactive waste management and radiation protection are focused on the following three general objectives: (i) modular approach and common qualification criteria, aiming at offering a coherent E&T framework with a wide variety of modules; (ii) a mutual and uniform accreditation system across the European Union (EU), using the European Credit Transfer and accumulation System of "Bologna"; (iii) facilitation of mobility for teachers and students, using also support from "private-public partnerships". In order to achieve the above objectives, the "European Nuclear Education Network" (ENEN, www.enen-assoc.org and enen.sec@cea.fr) was established in September 2003 as a non-profit association (under the French law of 1901), currently comprising 42 nuclear E&T institutions. ENEN aims towards creating a virtual European Nuclear University which might network education and training programs in all areas of nuclear fission and radiation protection.

The future of experimental nuclear installations has been identified by the EU as another major concern for the coming decades. Two major objectives need to be pursued, namely: (i) optimizing the use of existing infrastructures (networking, pooling, etc.), and (ii) renewing, when necessary, at the European level, ageing large infrastructures.

3. NUCLEAR (FISSION) ENERGY TECHNOLOGY PLATFORM

To ensure that the European Union retains its leading position in the field of civil nuclear technology, as emphasized in the Green Paper of March 2006, a Nuclear (Fission) Energy Technology Platform will be established in September 2007, bringing together representatives from all interested stakeholders, including: (i) research institutions**,** both public and private; (ii) utilities, as the end-users of nuclear power plants, as well as oil companies interested in process heat and the hydrogen market; (iii) nuclear industry, embracing reactor construction, fuel cycle and waste disposal; (iv) public authorities, in their roles of regulators (with the group of Technical Safety Organizations), policy makers, and promoters of technology development.

The main tasks of the envisaged Nuclear Fission Energy Technology Platform will be to: (i) develop a Strategic Research Agenda (SRA), coordinated at the European level, for ensuring that nuclear fission energy is generated in a manner that meets the criteria for sustainable development; (ii) guide the implementation of the SRA through coherently structured actions, on different time scales; (iii) provide expert advice and recommendations for strengthening the European scientific base, integrating research teams and RTD tools, optimizing the use of existing research infrastructures, and creating new infrastructures (as needed) aiming towards the creation of a European Research Area; (iv) create mechanisms for supporting trans-European synergy, emphasizing, in particular, the creation of a coordinated training and educational system for developing nuclear competence in Europe; (v) propose to the EU the preparation and implementation of the Framework Program; (vi) foster joint initiatives between researchers, industry, member states and the EU such as a Joint Undertaking; (vii) foster joint projects between member states; (viii) disseminate the results of the above activities to appropriate policy-making bodies, to ensure a common European vision.

The proposed structure for the Nuclear Fission Technology Platform is depicted in the diagram below:

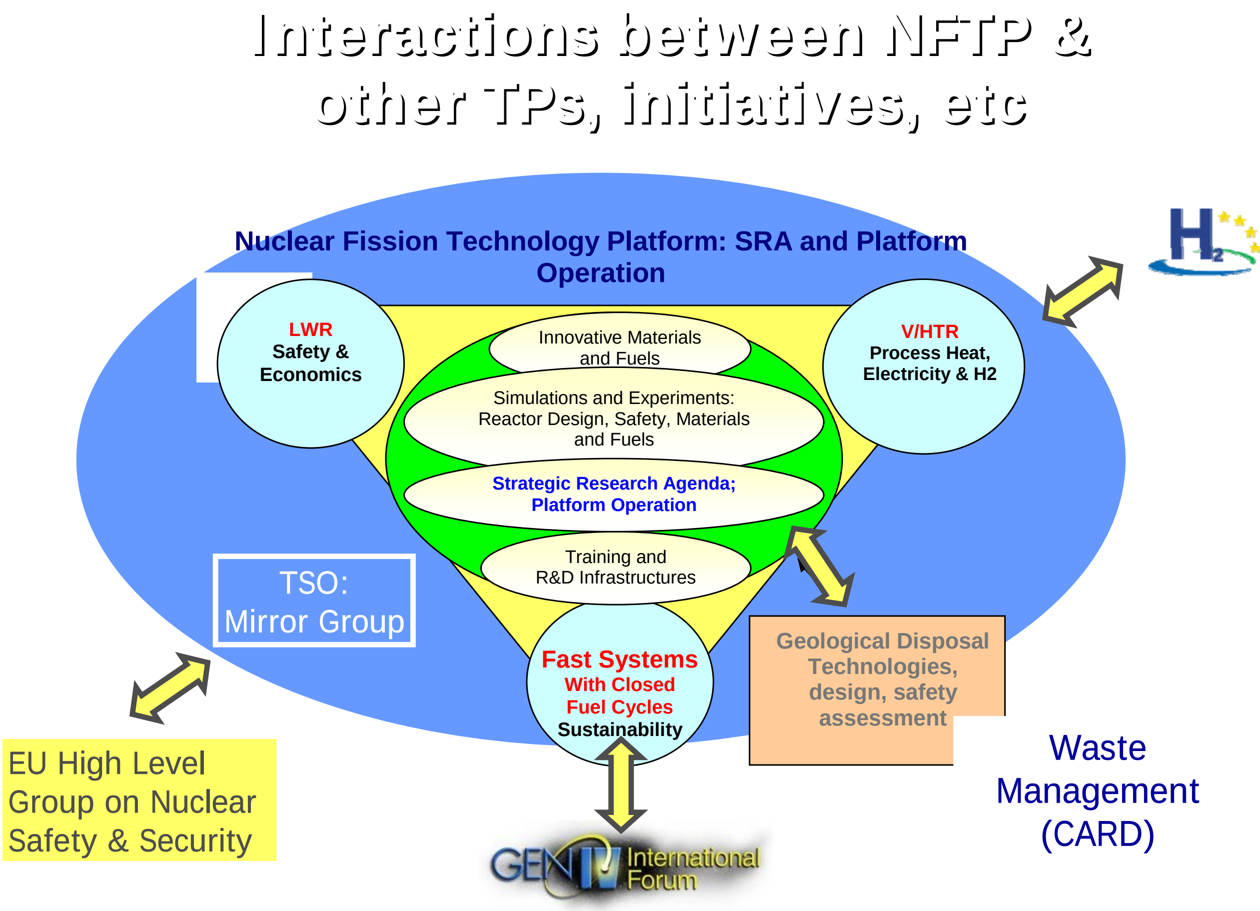

Figure 1. Illustrative structure for the proposed nuclear fission energy technology platform

4. VALIDATED SIMULATIONS AND EXPERIMENTS FOR REACTOR DESIGN, SAFETY, MATERIALS, AND FUELS

As is well known, a physical system and/or the result of an indirect experimental measurement are characterized by independent variables, dependent variables, and relationships between these quantities. Such relationships can be modeled mathematically in terms of: (a) linear and/or nonlinear equations that relate the system's independent variables and parameters to the system's state (i.e., dependent) variables; (b) inequality and/or equality constraints that delimit the ranges of the system's parameters; and (c) one or several quantities, customarily referred to as system responses (or objective functions, or indices of performance, or results of indirect measurements), which are to be analyzed as the parameters vary over their respective ranges. Mathematical models also include parameters whose actual values are not known precisely, but may vary within some ranges that reflect our incomplete knowledge or uncertainty regarding them. Furthermore, the methods needed to solve various equations numerically introduce themselves (numerical) errors. The effects of such errors and/or parameter variations must be quantified in order to assess the respective model’s range of validity. Moreover, the effects of uncertainties in the model’s parameters on the uncertainty in the computed results must also be quantified. Generally speaking, the objective of sensitivity analysis is to quantify the effects of parameter variations on computed results. Terms such as influence, ranking by importance and dominance, are all related to sensitivity analysis. On the other hand, the objective of uncertainty analysis is to assess the effects of parameter uncertainties on the uncertainties in computed results. Sensitivity and uncertainty analyses can be considered as formal methods for evaluating data and models because they are associated with the computation of specific quantitative measures that allow, in particular, assessment of variability in output variables and importance of input variables (see, e.g., Refs 2 and 3, and references therein).

Models of complex physical systems usually involve two distinct sources of uncertainties, namely: (i) stochastic uncertainty, which arises because the system under investigation can behave in many different ways, and (ii) subjective or epistemic uncertainty, which arises from the inability to specify an exact value for a parameter that is assumed to have a constant value in the respective investigation. Epistemic (or subjective) uncertainties characterize a degree of belief regarding the location of the appropriate value of each parameter. In turn, these subjective uncertainties lead to subjective uncertainties for the response, thus reflecting a corresponding degree of belief regarding the location of the appropriate response values as the outcome of analyzing the model under consideration. A typical example of a complex system that involves both stochastic and epistemic uncertainties is a nuclear power reactor plant: in a typical risk analysis of a nuclear power plant, stochastic uncertainty arises due to the many hypothetical accident scenarios which are considered in the respective risk analysis, while epistemic uncertainties arise because of the many uncertain parameters that underlie the estimation of the probabilities and consequences of the respective hypothetical accident scenarios.

Sensitivity and uncertainty analysis procedures can be either local or global in scope. The objective of local analysis is to analyze the behavior of the system response locally around a chosen point or trajectory in the combined phase space of parameters and state variables. On the other hand, the objective of global analysis is to determine all of the system's critical points (bifurcations, turning points, response maxima, minima, and/or saddle points) in the combined phase space formed by the parameters and dependent (state) variables, and subsequently analyze these critical points by local sensitivity and uncertainty analysis. The methods for sensitivity and uncertainty analysis are based on either deterministic or statistical procedures. In principle, both types of procedures can be used for either local or for global sensitivity and uncertainty analysis, although, in practice, deterministic methods are used mostly for local analysis while statistical methods are used for both local and global analysis.

Two conceptual paths are currently used by nuclear utilities and Technical Safety Organizations (TSO) to demonstrate that the nuclear power plants are designed to respond safely to all postulated accidents scenarios. The first conceptual path involves the use of so-called “conservative” simulation code systems, which contain deliberate pessimisms and unphysical assumptions; it is then argued that the overall predictions from such “conservative” simulations are worse than reality. The second conceptual path involves the use of so-called “best estimate” simulation codes, in which “best estimate” input data is utilized to obtain a “best estimate” result. The use of best-estimate codes is motivated by both safety and economical reasons, particularly since the “conservatism” of results produces by conservative simulation codes is not simple to prove (due to canceling effects, presence of counter-reactions, etc). Moreover, the use of best-estimate codes allows a better understanding of the progression of hypothetical accident scenarios, thus leading to improved accident management procedures. Best-estimate codes also make it possible to relax certain technical specifications and core operating limits set by conservative calculations. However, when such best-estimate simulations are performed for safety studies and for evaluating safety margins around the best-estimate values, it is simultaneously necessary to value (or to overvalue) the uncertainty attached to the best-estimate result obtained from the respective simulations.

Most of methods currently used by utilities and or TSOs can be roughly decomposed in four sequential steps. The end-status of each step determines if the next step is performed or not. The first step is devoted to analyzing the code’s applicability and identifying uncertain parameters and important phenomena of the transient scenario under consideration. On this basis, the code’s predictive capability is verified against the model’s inventory, the model’s origin and background. Finally, one identifies the output variables (i.e., results) of interest for post-processing. The second step is devoted to reviewing the correlations that involve the uncertain parameters, and identifying the parameter that are potentially significant for the physical phenomena observed during the transient scenario under consideration. This (second) step thus corresponds to a “sensitivity analysis”. In the third step, experimental uncertainties of the initial and boundary conditions and expert judgment (supported, when available by the “code qualification test-experiment matrix”) are employed to obtain uncertainty bands and subjective probability density functions for the uncertain parameters. In the fourth step, the various uncertainties are combined probabilistically via “response surface methods” (see, e.g., Ref 3) in order to derive “uncertainties” for the results of interest. Examining carefully all of these steps clearly reveals that a significant amount of conservatism remains embedded even in the “best-estimate” codes, and that the “code validation and qualification” processes are not yet entirely objective. In particular, it seems necessary to incorporate concepts of data adjustment and assimilation [4] into the construction, validation and qualification of best-estimate simulation tools.

As depicted symbolically in Figure 1, above, numerical simulations and validation activities comprise transversal activities common to all types of reactors, as well as issues which are specific for each type of reactor system. Important activities towards the development of validated simulation tools within ongoing European projects concern the development of (i) numerical modeling tools to simulate the effects of irradiation on the mechanical and corrosion behavior of nuclear materials, aiming at reducing uncertainties and establishing safety margins by comparison to empirical component analyses; and (ii) simulation tools for core physics, thermal-hydraulics, fuels, structures. The prediction of the combined effects of irradiation and corrosion on reactor internals and/or claddings requires the development and qualification of multi-scale simulation tools that bridge atomic (nanometers), mesoscopic (micrometers), and macroscopic (centimeters) scales, along with the experimental validation of these tools. Such multi-scale tools are being development within the EURATOM collaborative projects PERFECT. Simulation tools for core physics, thermal-hydraulics, fuels, structures, and materials are currently developed within the EURATOM project NURESIM. Issues currently addressed include: (i) coupling of core physics and thermal hydraulics models for reactor safety; (ii) addition of models related to fuel behavior and structural mechanics; (iii) sensitivity and uncertainty analysis using deterministic and statistical methods; continued development is needed to combine the strengths of the deterministic and statistical methods in order to eliminate as many of their respective limitations as possible; (iv) experimental validation, using industrial plant data and results of existing or new experiments, as necessary, in order to qualify the models, in addition to other means of validation such as benchmarking with other qualified calculation codes when available. The validation and qualification of numerical simulations against experiments requires the inclusion of methods of sensitivity and uncertainty analysis together with data assimilation in the presence of both computational and experimental uncertainties.

The development of numerical simulation tools for reactor design, life extension, and safety is facilitated by the use of the same software platform, called SALOME, which facilitates the exchange of solvers and data across sites, as needed for performing multi-physics and multi-scale computations. The integrating role of SALOME and the evolution of SALOME towards High Performance Computing (HPC) are important features. A roadmap for the development, validation and qualification of simulation tools fro reactor design, life extension, and safety is illustrated in the figure below. Closely related is the development of “*Advanced Safety Assessment Methodologies*” for best practice guidelines for the performance of Level-2 PSA methodologies, with a view to harmonization at the EU-level, leading to a meaningful and practical uncertainty evaluation in a Level-2 PSA. Close collaboration with nuclear regulators is essential in order to use Level-2 PSA methodologies with greater confidence for the further development of severe accident management procedures.

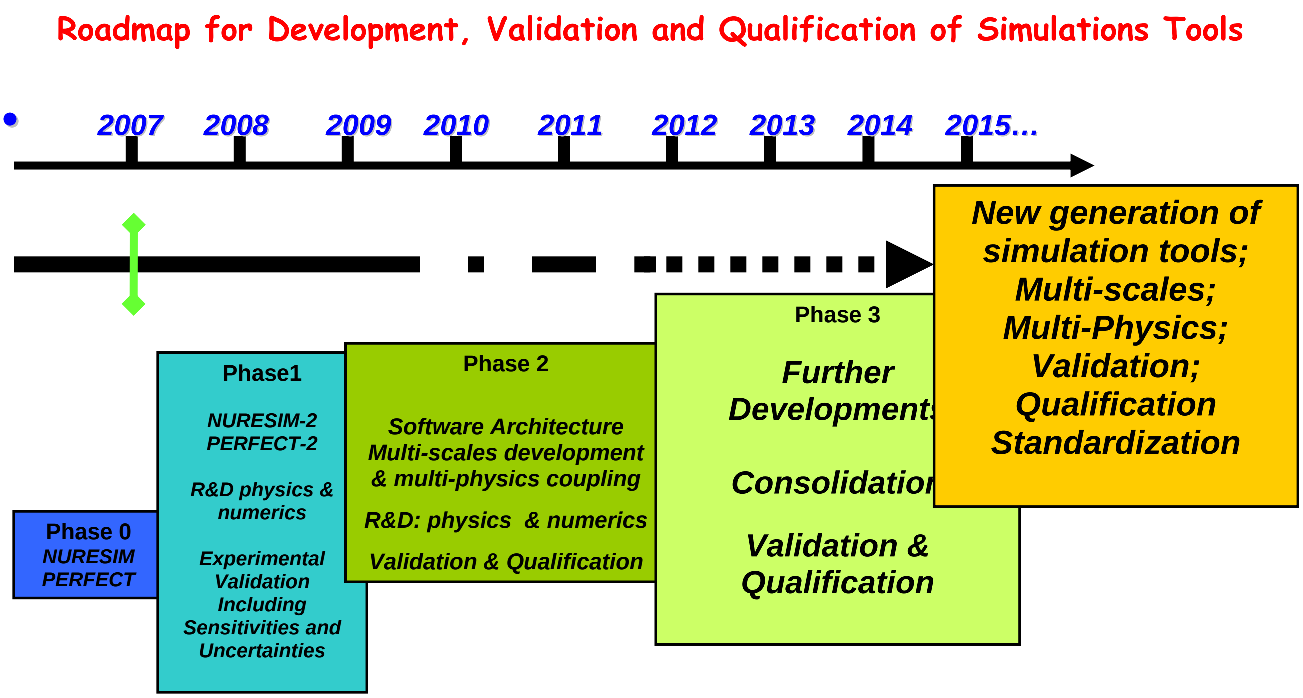

Figure 2. Roadmap for development, validation and qualification of simulation tools

5. CONCLUSIONS

The objectives of the European R&D for energy for the next five years are to commence the transformation of the current fossil-fuel based energy system into a more sustainable one, based on a diverse portfolio of energy sources and carriers combined with enhanced energy efficiency, to address the pressing challenges of security of supply and climate change, whilst increasing the competitiveness of Europe's energy industries. In order to reach the vision of sustainable nuclear energy in Europe, the Partners of the EU-FP6 Coordination Action "Sustainable Nuclear Fission Technological Platform" (see Ref. 1, below) recommend the establishment of a nuclear fission technology platform as the preferred instrument for mobilizing and pursuing nuclear fission-related initiatives, programs and policies for bringing together all stakeholders from science, industry, safety and policy areas, with the following specific goals:

- Implement the Strategic Research Agenda, in which the main research and development issues in nuclear science and technology are to be addressed and coordinated for the coming decades. To achieve the goal of sustainability for nuclear fission energy, research investment, continuity and coherent coordination are necessary. Nuclear fission R&D should be supported through both European and national funding mechanisms. The SRA should foster an interdisciplinary approach to the sustainable development of nuclear fission energy.

- Coordinate ongoing research in nuclear energy (fission) in Europe with the assistance of a Mirror Group of Member States and the input from the group of Technical Safety Organisations. European and national programs should be reviewed to assure adequate cooperation.
- Coordinate and optimize the use of instruments and resources to encourage investment in research, innovation and education in nuclear science and engineering.
- Foster joint initiatives between researchers, industry, Member States and the EU, and develop a comprehensive communication activity involving a broad range of stakeholders and the public in the Member States.
- Create mechanisms for supporting trans-European synergy, emphasizing, in particular, the creation of coordinated training and educational system for developing nuclear competence in Europe.

The development of software modules for validation and verification of simulation programs, including global sensitivity and uncertainty analysis, is a generic issue of fundamental importance for the safe operation of all types of reactors, while allowing reductions in design margins. Numerical simulations comprise transversal activities common to all types of reactors, and also include specific issues concerning specific types of reactor systems. Besides performing specific experiments and developing specific simulation models, essential activities are "code verification" ("is the code solving the mathematical model correctly?"), "code validation" ("does the model represent reality?"), and "code qualification" (certifying that a proposed simulation/design methodology/system satisfies all performance and safety specifications). Code validation and qualification (V&Q) can be attained only by selected benchmarking, taking into account systematically (i.e., using sensitivities) all sources of uncertainties (computational, experimental, etc.). The development of standardized validated and qualified tools for numerical simulations is therefore considered to be a key activity for the future of nuclear energy in Europe.

REFERENCES

1. "Sustainable Nuclear Fission Technology Platform (SNF-TP)", EURATOM Contract Nr. FP6-036410, July 2006, European Commission, Brussels.
2. D.G. Cacuci, *Sensitivity and Uncertainty Analysis: Theory*, **Volume 1**, Chapman & Hall/CRC, Boca Raton, 2003.
3. D.G. Cacuci, M. Ionescu-Bujor, and M.I. Navon, *Sensitivity and Uncertainty Analysis: Applications to Large Scale Systems*, **Volume 2**, Chapman & Hall/CRC, Boca Raton, 2005.
4. D.G. Cacuci, M.I. Navon, and M. Ionescu-Bujor, *Computational Methods for Data Analysis and Assimilation*, Chapman & Hall/CRC, Boca Raton, 2007.