Minutes of International Workshop on Reactor Physics Advances for Design and Analysis of Generation IV Nuclear Energy Systems Hyatt Regency Hotel, Chicago, IL, April 30, 2004

Introduction

An international *Workshop on Reactor Physics Advances for Design and Analysis of Generation IV (Gen IV) Nuclear Energy Systems* was held at the Hyatt Regency Hotel, Chicago, IL, April 30, 2004. This workshop took place immediately following the PHYSOR 2004 International Reactor Physics Conference, April 25-29, 2004. Approximately 100 participants from fifteen countries (Belgium, Britain, Canada, France, Japan, Lithuania, Mexico, Netherlands, Republic of Korea, Russia, Spain, South Africa, Sweden, Switzerland, and U.S.A) attended the workshop. Representatives of international organizations (OECD/NEA and European Commission) also participated.

The objectives of the workshop were:

- Exchange information on multi-national basis on perspectives and efforts related to reactor physics of Gen IV systems
- Identify priorities as currently perceived and topics of common interest
- Define opportunities and approaches for bi-lateral or multi-lateral cooperation

The workshop was composed of two parts: presentations by country representatives in the morning, and open discussions in the afternoon. The Workshop Agenda is provided as Attachment A. The country presentations from France, Japan, Republic of Korea, European Community, and the U.S. addressed or covered (1) current R&D activities, (2) future plans, and (3) proposals for international collaboration. The afternoon discussion sessions were moderated by participants from U.S. laboratories (ORNL and INEEL) and CEA (France).

Country Presentations

H. Khalil, the U.S. National Technical Director (NTD) for Gen IV Design and Evaluation Methods chaired the workshop. In his introductory remarks, he noted that reactor physics capabilities are not seen as a feasibility issue in the Gen IV program. However, because the U.S. Next Generation Nuclear Plant (NGNP) initiative is targeting a more aggressive development pace, there is a need to improve existing tools and their validation status in order to support design optimization and licensing. He noted that reactor physics analysis is an integral part of design/safety projects and highly relevant to other projects as well (fuels, fuel cycle, materials). Reactor physics areas of common interest to most of the Gen IV nuclear energy systems were identified as actinide data for fast reactors operated in closed fuel cycle, modular or general purpose code systems, and improved Monte Carlo capabilities. Approaches for bi-lateral or multi-lateral cooperation were proposed: (1) Sharing of datasets and computer codes; (2) Joint analysis of benchmarks and inter-comparison of codes; (3) Joint definition of required/desired advances (with consideration of target accuracies); (4) Coordinated compilation and assessment of data (e.g., integral measurements); (5) Coordinated development of new models; (6) Joint planning and execution of experiments on existing facilities; and (7) Joint definition of needs for new measurements and supporting facilities.

R. Jacqmin (CEA, France) noted that innovations in PWRs and development of Gen IV nuclear system were two major R&D directions in France in the broad area of innovative reactors, fuels, and fuel cycles. The CEA Gen IV reactor physics activities are largely focused on the GFR; they include the definition and safety analysis of the reference concept and backup options, design and evaluation of the

Experimental Research and Technology Demonstration Reactor (ETDR), development and validation of calculation tools, and economic assessments. In order to support the development of the ETDR and a prototypic GFR, a reactor physics integral experimental program (ENIGMA) is being planned in the MASURCA facility. This multi-year program, which is to begin in 2005, is part of the European Community (EC) 6th Framework Program proposal and open to external participation. The French side is interested in international participation, particularly contributions to proposed measurements and measurements techniques within the program.

A presentation on *Recent Development of Fast Reactor Analysis System in Japan* was given by T. Hazama (JNC, Japan). The plan for the feasibility study on fast reactor fuel cycle, which extends from 2000 to 2015, was discussed along with reactor physics related issues (methods development and improvements). He noted that the ERRORJ code which produces group-averaged covariance data from those contained in the evaluated nuclear data file has been made available to the international nuclear community, through the OECD/NEA and RSICC. He also discussed the SLAROM-UF cell code that has resulted in improved predictions of core physics parameters.

The U.S. presentation summarized the findings of the two reactor physics and nuclear data workshops that were held in the U.S. in 2003. The reactor physics issues and development needs identified for the Gen IV systems at the workshops were discussed by T. Taiwo (ANL, USA). He noted that while existing neutronic analysis tools may be largely adequate for early pre-conceptual design development and viability phase evaluations, improvements are needed for the performance phase. Priority should be placed on identifying previous integral experiment measurements of greatest relevance to advanced systems and on documenting/preserving their specifications and measured results. When necessary, additional experiments should be defined to address significant deficiencies that may exist in the available experimental database. The Coupling of neutronic, thermal-hydraulic (T-H), fuel behavior, and structural models should be planned and accommodated in the early stages of code development or adaptation. There is also a need to define target accuracies for core performance parameters such as criticality, power distribution, and reactivity parameters. He noted observed differences in cross section data obtained from different evaluated nuclear data files, particularly for the higher transuranics (Pu, Np, Am and Cm). There is a need to systematically identify and quantify these differences as they relate to Gen IV systems, using sensitivity and uncertainty analysis techniques. These differences are more pronounced for Gen IV systems relative to LWRs because of the non-conventional fuel, structural or fuel-matrix materials being considered for the advanced systems. Taiwo also discussed the proposal made to the OECD/NEA IRPhE project in December 2003 to establish a sub-group devoted to the evaluation of experimental data being collected under the project, in order to identify those pertinent to the verification and validation of Gen IV reactor physics analysis tools.

The *Status and Requirements of Gen IV Reactor Physics Studies in Korea* was presented by Chang-Hyo Kim (Seoul National University, ROK). He noted that the VHTR, SFR, and the Supercritical Water-Cooled Reactor (SCWR) were the Gen IV systems of current interest to ROK. He discussed various VHTR, SFR and SCWR reactor physics studies, which have included the construction of a website (www.hydrogen.re.kr), installation and assessment of the VSOP94 code, performance of pebble flow experiment using a test miniature, preconceptual design studies for VHTR systems, the KAERI KALIMER design projects, development and validation of an alpha-version SCWR physics code, and conceptual design of an SCWR fuel assembly. The development of an advanced lattice code (DeCART) and Monte Carlo capability with error propagation and thermal feedback was also described by Prof. Kim.

F. J. Hambsch (EC-JRC-IRMM, Belgium) gave a talk on *Nuclear Data Needs for Gen IV* systems. These needs include data for plutonium and minor actinides (needed to characterize irradiated fuel, including radiation emission characteristics); cross section data for non-conventional coolants (e.g., Pb, Bi), structural materials, and fuel matrix materials (e.g., Zr, Mg, Ti), gas generation (H and He), and radiation

damage data; evaluation of nuclear data uncertainties and their correlations (covariances); and reliable Doppler broadening of specific isotopic cross sections. He noted that for some of the nuclides there are large uncertainties in data files due to lack of sufficient, high-quality experimental data. The European facilities for neutron physics measurements were also discussed. These facilities provide European safety authorities and industry with neutron data needed for the safety assessment of nuclear reactor and fuel cycle installations and for studies of the feasibility of advanced waste transmutation systems and processes. Hambsch noted the planning for an upcoming workshop on nuclear data for Gen IV systems that is being organized by the EC-JRC-IRMM and the U.S. DOE.

Discussion Sessions

In addition to the foregoing presentations, two topics were addressed in the subsequent discussions: (1) *Advanced Reactor Physics Methods and V&V of Physics Tools* and (2) *Nuclear Data Needs and Developments*. These discussions were led by D. Nigg (INEEL, USA) and G. Rimpault (CEA, France), respectively. A final session devoted to "Recommendations and Wrap-up," was led by D. Ingersoll (ORNL, USA).

The need to educate future users of reactor physics tools was identified. Approaches for achieving this goal were discussed, including implementation of an educational training structure in conjunction with the Gen IV program, organization of workshops on codes, using existing training structures (such as the reactor physics FJOH summer school organized by CEA and FZK in Europe), and development of more intelligent analytical tools that capture expertise in a user-friendly way. Assignment of students or trainees at recognized centers of excellence in defined reactor physics areas was also proposed as a valuable and cost effective approach.

Efficient use of funding available for improvement of capabilities motivates increased cooperation between countries. Mulder (PBMR, South Africa) identified the need to establish a mechanism for exchange of nuclear data for high temperature operation and the definition of benchmark problems for verifying and validating the data. He noted that the Coordinated Research Project (CRP) on high temperature reactors (HTRs), undertaken as part of an IAEA program, was coming to an end and that there is a need to define another activity to replace this task. M. Salvatores (ANL and CEA) noted the coordination activities by the OECD/NEA. He suggested that the OECD/NEA forum might be well suited for the Gen IV program, particularly given its flexibility and experience organizing cooperative activities such as joint benchmarking of computer methods. He indicated that activities can be initiated relatively quickly under the auspices of the OECD/NEA Nuclear Science Committee (NSC). Salvatores also noted that if an initiative is considered of interest, the OECD/NEA could form a *working party* for the activity. R. Jacqmin noted that there is a working party within the OECD/NEA that is currently assessing nuclear data needs for current and future systems (including Gen IV).

R. Chawla (PSI, Switzerland) indicated the need to inventory international codes in order to facilitate code exchanges. Khalil noted that such code exchanges would generally require a bi-lateral or multi-lateral mechanism. C. de Oliveira (Georgia Tech, USA) suggested that a single source deterministic code might not be applicable for the analysis all Gen IV systems. The interested countries have to work on analysis capabilities for different Gen IV systems collectively. Effective utilization of the product might necessitate standardized codes with modular architecture. The development of multi-physics capabilities was also suggested as a way of ensuring that reactor physicists maintain cognizance of other disciplines and can lead or contribute to advancing the state-of-art in representing coupled phenomena. The multi-physics capability would have neutronics, thermal-hydraulic, thermo-mechanical and fuel analysis modules. Such capabilities are being developed in other system design disciplines. A cautionary note on code exchanges was provided by Reitsma (NECSA, South Africa). He noted the need for diversity as a means of providing independent checks for codes and data.

S. Baker (U.S.) noted the need for joint planning and experiments that could support Gen IV designs. A standardized approach for documenting data should be defined. Khalil confirmed that the Gen IV performance goals put a great demand on physics tools and their expert application to development of designs. It is important to be able to evaluate how well the tools are performing. M. Feltus (US-DOE) added that it was important to demonstrate how nuclear data needs and other desired improvements of analysis capabilities can affect the design of Gen IV systems.

G. Rimpault (CEA) indicated that determining the R&D needs for Gen IV reactor cores requires the assessment of code development activities, nuclear data, thermal-hydraulic capabilities, experimental validation, and data uncertainty. He noted that the work to be performed for Gen IV reactor cores should only build on existing knowledge. Otherwise, the work would be too much for the current funding level. To accomplish the necessary extension, methods should be sufficiently well assessed so that nuclear data knowledge acquired for PWR and other Gen III systems could be used for thermal systems under consideration in Gen IV, i.e., VHTR and SCWR. A similar approach should be used for Gen IV fast systems accounting for the nuclear data assessment for current LMFRs. For the fast systems, nuclear data evaluations only would unlikely meet the target accuracies required for the designs, it is therefore important to use the complete database of existing integral experiment data. It was recognized that the validation of evaluated nuclear data needed to incorporate greater quality assurance (QA). Progress has been made with this in the recent evaluations. Particular attention should however be given to the completeness of the files, for instance the gamma production matrices which are often missing in current evaluations. Based on this incremental approach to nuclear data needs, the important role of sensitivity and uncertainty analysis was re-iterated. It was additionally noted that depletion dependent sensitivity calculation tools would be required. Salvatores pointed out that target accuracies and sensitivity and uncertainty calculations can be readily performed for the systems of primary importance (e.g., VHTR in the U.S. or GFR in France). It was felt that this effort should be undertaken in the near future and broadened as it is the only way to overcome the lack of available experiments for current designs.

R. Jacqmin noted the diversity in systems that are of primary interest to the countries involved in Gen IV activities. The French CEA has plans to initiate a GFR physics experiment (ENIGMA). Khalil noted that the current U.S. approach for the VHTR is to review existing data and identify relevant ones for code verification and validation. This assessment might identify a need for additional experiments since the pedigree of the old data might not support the desired confidence in the tools.

P. Finck (ANL, USA) noted that in general, the list of nuclear data that needed re-assessment has not changed greatly in recent years. He suggested that the lack of funding, expertise, and political will might be reasons why these tasks have not been completed. Hambsch noted that nuclear data requests have to be synchronized with capabilities. However, the program emphasis has varied in recent years, such that the data-need list becomes obsolete very quickly (before experiments are completed). Nigg noted the attempt to prioritize data needs under the U.S. Advanced Fuel Cycle Initiative (AFCI). Salvatores suggested that the data needs for the Gen IV systems might be a short one and that the aforementioned sensitivity and uncertainty analysis would readily reveal the pertinent needs. Rimpault mentioned that such a work is being performed within the OECD/NEA group, to which he belongs, defining a High Priority Request List. The objective of that group is to limit the list to those requests for which needs have been clearly identified. The list will contain the applications for which the request is required, evidence that this data has an influence of the core characteristics (target accuracies of the design should be defined) and eventually potential proof that existing nuclear data are leading to discrepant results when analyzing integral experiments. The covariance data needed for this evaluation have to be provided in a form useful to the core physics analyst; they should have input to the pertinent data being produced. M. Feltus noted that U.S. facilities for performing physics experiments and obtaining nuclear data are in danger of being lost (shutdown).

Recommendations from Discussions

The Workshop discussions resulted in the recommendations summarized below:

- The various needs identified by the U.S. reactor physics and nuclear data workshops of FY2003 are consistent with those of interest to the international community. These include:
    - Input data
        - New nuclear data (reactions, decay, yields, dpa)
        - Covariance data
        - Data processing
    - Simulation tools
        - Micro (fuel kernel) to macro (whole core) physics modeling (deterministic/stochastic/hybrid)
        - Neutron-gamma coupled capabilities
        - Coupled multiphysics methods (neutronics/T-H/structural/fuel behavior)
    - Code and data verification and validation
        - Benchmark recapture and evaluation
        - New benchmarks
        - Sensitivity/uncertainty methods (recapture and standardized)
    - Enablers and context
        - Understanding/communicating the impact of reactor physics activities, including economics
        - Licensing expectations and issues

- Various avenues for international collaborations were identified
    - The planned CEA GFR ENIGMA experiment that is open to international participation
    - IAEA CRPs on sodium-cooled fast reactors and gas-cooled high temperature reactors
    - ISTC proposals which might provide integral experiment data for lead and molten salt cores
    - OECD/NEA activities and working parties
        - Existing projects such as IRPhE that is devoted to the preservation of past experimental measurements
        - New projects within the framework of existing working parties; e.g., Working Party on International Nuclear Data Evaluation Cooperation (WPEC), Working Party on the Physics of Plutonium Fuels and Innovative Fuel Cycles (WPPR)
        - New working party explicitly geared to coordination of Gen IV reactor physics work. Potential activities include review of integral experiments, definition of new benchmarks, and initiation of activities on sensitivity and uncertainty methods for data and application
    - The national leads for Gen IV design and evaluation methods activities should explore with their respective Gen IV systems steering committee members the feasibility of coordinating the Gen IV reactor physics activities through international organizations such as the OECD/NEA.

Attachment A
Workshop on Reactor Physics Advances for Design and Analysis of Generation IV Nuclear Energy Systems, April 30, 2004

Purpose

Six nuclear energy systems have been selected for development under the Generation IV nuclear system initiative. The reactor technologies used in these systems are the Very High Temperature Reactor (VHTR), Supercritical Water-Cooled Reactor (SCWR), Gas-Cooled Fast Reactor (GFR), Lead-Cooled Fast Reactor (LFR), Sodium-Cooled Fast Reactor (SFR), and Molten Salt Reactor (MSR). These systems target significant advances over current generation and evolutionary systems in the areas of sustainability (encompassing waste generation and resource utilization), economics, safety and reliability, and proliferation resistance and physical protection. Reactor concept development and core design (including reactor physics) studies are ongoing for these systems in several countries. Analytical tools for evaluating the systems are also being developed. The intent of this Workshop is to have international experts present/discuss ongoing research and development activities in the design and evaluation of the advanced nuclear systems. Core physics design and nuclear data needs and issues will be discussed along with proposals for international collaborations for meeting these needs.

This one-day workshop will have presentations and discussion sessions. The workshop is co-located with the PHYSOR2004 Topical Meeting, April 25-29, Chicago, Illinois, USA.

LOCATION AND DATE: Hyatt Regency Hotel, Chicago, Illinois, U.S.A, April 30, 2004

WORKSHOP ORGANIZERS

Dr. H. S. Khalil, Director, Nuclear Engineering (NE) Division, ANL and National Technical Director, Design and Evaluation Methods, U.S. Gen IV Program
Dr. R. Jacqmin, Research Director, Nuclear Energy Division, CEA, France.
Dr. T. A. Taiwo, Manager, Nuclear Systems Modeling Section, NE Division, ANL, U.S.A.

AGENDA

8:30 – 8:45 a.m.	**Introductory Remarks – Hussein S. Khalil (ANL)**
	INTERNATIONAL PERSPECTIVES AND PROPOSALS
8:45 – 9:15 a.m.	**France: Gas-cooled Reactor Core Physics R&D Activities in France – Robert Jacqmin (CEA)**
9:15 – 9:45 a.m.	**Japan: Recent Development of Fast Reactor Analysis System in Japan – Taira Hazama (JNC)**
9:45 – 10:15 a.m.	**U.S.: Summary of Gen IV Reactor Physics Workshops –Temitope Taiwo (ANL)**
10:15 – 10:30 a.m.	**Break**
10:30 – 11:00 a.m.	**ROK: Gen IV Reactor Physics Developments – Chang Hyo Kim (Seoul Natl. Univ.)**
11:00 – 11:30 a.m.	**EC Involvement in Nuclear Data Needs for Gen IV Systems – Franz-Josef Hambsch (EC-JRC-IRMM)**
11:30 – 1:00 p.m.	**Lunch/Break**
	DISCUSSION AND RECOMMENDATION SESSIONS
1:00 – 2:30 p.m.	**Advanced Reactor Physics Methods and V&V of Physics Tools – lead: David Nigg (INEEL)**
2:30 – 4:00 p.m.	**Nuclear Data Needs and Developments – lead: Gerald Rimpault (CEA)**
4:00 – 5:00 p.m.	**Recommendation and Wrap-up Session – lead: Dan Ingersoll (ORNL)**
5:00 p.m.	**Meeting Adjourns**