Overview of the Nuclear Energy Agency Scientific Activities on Advanced Fuel Cycles

S. Cornet[1], N. Chauvin[2]

[1]Nuclear Energy Agency (NEA), Paris, France

[2]Commissariat à l'Energie Atomique et aux Energies Renouvelables (CEA), Cadarache, France

E-mail contact of main author: stephanie.cornet@oecd.org

Abstract.

Activities related to the fast reactors systems at the Nuclear Energy Agency (NEA) mainly focus on scientific research and technology development needs and are carried out within the Nuclear Science Division. In particular, projects related to the advanced nuclear systems and fuel cycles are carried out through the Working Party on Scientific Issues of the Fuel Cycle (WPFC) and its five related experts groups covering all scientific aspects of the fuel cycle from front to back-end. Ongoing projects on advanced systems include fuel cycle scenarios, fuels, materials, physics and chemical separations. Members of the expert groups cooperate to share recent research advancements at an international level and help identify gaps and needs in the field.
Current activities focus on nuclear systems in particular on the challenges associated with the adoption of new materials and fuels such as for example cladding materials, fuels containing minor actinides, or the use of liquid metal as coolants. At the back-end, chemical separations technologies for recycling in fast reactors are being reviewed.

Key Words: Advanced Fuel Cycles, International cooperation, fuel cycle scenarios, fuels, materials, separation chemistry

1. Introduction

The Nuclear Energy Agency (NEA) is an international organization established to assist its member countries in developing the scientific, technological and legal bases required for the safe and economical use of nuclear energy for peaceful purposes. Within this mission, the NEA supports studies related to the development of advanced nuclear systems and fuel cycles including fast reactor systems, covering both technical and strategic issues. Most of the work is carrying out under the auspices of the Nuclear Science Committee (NSC) and the Working Party on Scientific Issues of the Fuel Cycle (WPFC).

The mission of NEA NSC is to help member countries identify, collate, develop and disseminate basic scientific and technical knowledge required to ensure safe, reliable and economic operation of current nuclear systems and to develop next-generation technologies. The committee comprises several working parties where experts performed numerous activities to (1) help advance the existing scientific knowledge needed to enhance the performance and safety of current nuclear systems; (2) contribute to building a solid scientific and technical basis for the development of future-generation nuclear systems; and (3) support the preservation of essential knowledge in the field of nuclear science.

The WPFC covers all aspects of the fuel cycle from front to back end. Ongoing projects are mainly dedicated to the development of technologies for advanced systems and include fuel cycle scenarios, fuels, materials, coolants and chemical separations.

2. Advanced Fuel Cycle Scenarios

Fuel cycle scenario analysis is a common method for identifying and communicating potential nuclear energy futures, especially when assessing the impact of new technologies. System codes are used to assess the behaviour of different nuclear energy systems and to examine scenarios involving transition of infrastructure (reactors, fuel cycle facilities, etc.) to accommodate growth and adopt new fuel cycle management approaches (e.g. recycling).

By their nature, scenario analyses involve assumptions about the future, and the systems codes used in scenario analyses are imperfect representations of the real world. Uncertainties inherent in scenario specifications and system codes impact the accuracy of analyses. There are several sources of uncertainty in fuel cycle analyses using system codes, including scenario assumptions, facility operational values, reactor core physics calculations, etc., and their impacts vary based on the fuel cycle and the performance metrics of interest. The Expert Group on Advanced Fuel Cycle Scenarios (EGAFCS) recently completed an activity that used sensitivity studies to evaluate the impact of uncertainty of the primary scenario input parameters on scenario results [1]. The purpose of this study was to identify these sources of uncertainty and use sensitivity studies to assess their impacts on system level results.

A current study aims at investigation the management of transuranic in order to evaluate how much of the materials in spent fuel can be burnt using various “burner fleets” including Gen IV systems (SFR, GFR, LFR, etc).

3. Materials and Fuels

NEA activities on materials for fast reactor systems provide the necessary support to the development of innovative fuels and structural materials needed for the development of new technologies with fast spectrum and different coolants (liquid metal or helium). A large spectrum of subjects is covered, from fundamental R&D on modelling methods to reviews on innovative fuels and structural materials and databases. The NEA also supports the organization of workshops in the field of innovative material research.

3.1 Modelling methods

The Working Party on Multi-scale Modelling of Materials (WPMM) aims at providing an assessment of the possibilities and limits of numerical methods applied to multi-scale modelling, with a specific focus on the applications to future development of fuels, the modelling of irradiations in structural nuclear materials and an attempt to validate these methods with appropriate benchmarks. In particular, activities focus on [4]:

- Atomistic modelling and simulation of fuels for advanced nuclear systems, specifically including aspects related to first principles description of the actinide bearing phases;
- Atomistically informed modelling and simulation of nuclear fuels and structural materials at progressively longer time and length scales, focusing on radiation damage effects and on the methodologies needed to achieve multi-scale integration;
- Verification and validation of simulations and model predictions through uncertainty analysis, evaluation of approximations, code benchmarking, analytical solutions, and experimental data;

- Development of new applied mathematics and software tools, particularly those of common interest for fuels and structural materials;
- Integration of results from multi-scale modelling and simulation into performance codes and materials qualification processes.

3.2 Materials

Key technologies for innovative systems such as Gen Iv encompass the development of high temperature structural materials.

The Expert Group on Innovative Structural Materials (EGISM) conducts joint and comparative studies to support the development, selection and characterisation of innovative structural materials that can be implemented in advanced nuclear fuel cycles, under extreme conditions such as high temperature, high dose rate and corrosive chemical environment and long service lifetime. A review on innovative cladding and structural materials being developed for SFRs, lead cooled fast reactors (including accelerator driven systems) and gas cooled fast reactors (GCRs) was published in 2013 [2]. Current activity involves the preparation of a report the grand challenges for adoption of innovative materials in modern reactor applications.

The fourth edition of the International Workshop on Structural Materials for Innovative Nuclear Systems (SMINS) was held in July 2016 in Manchester (UK). This workshop promotes exchange of information on structural materials R&D, covering fundamental studies, advanced modelling and experiments

3.3 Fuels

Minor actinide bearing fuels

The dawn of advanced nuclear systems requires further insights into the new types of fuel and materials that are currently being developed for use in these systems. An understanding of the technical issues associated with the implementation of innovative fuels (oxide, metal, nitride, carbide fuels, ADS fuels) and clad materials for use in advanced fuel cycle is necessary. To gain further understanding, the NEA has launched a study on these fuels, especially those that contain minor actinides as opposed to standard fuels.

A review on the current status of innovative fuels was published in 2014 by the Expert Group on Innovative Fuels [3]. The report focus on minor actinides (MA) bearing fuels; all solutions from oxide, to carbide, nitride, metal, dispersion fuels and special mechanical fuels (sphere-pac, vibro-pac) were considered, including an evaluation of the technical readiness level for fabrication and irradiation performances.

Members of the expert group are currently working on a benchmark study on MA containing fuel performance codes focusing on minor actinide bearing oxide and metal fuels. Selected oxide and metal fuels irradiations test are being considered. Phase 1 of the benchmark is currently being finalised. Phase 2 will cover the study transient behaviour for the current range of innovative fuels. An additional activity on fuel properties for fast reactors was suggested in order to:

- identify the properties needed for fuel performance codes;
- recommend available data with uncertainties;
- recommend a law with parameters for each property and;

- identify missing data.

Thermodynamic Data of Advanced Fuels

The project on Thermodynamic Data of Advanced Fuels — International Database (TAF-ID), externally funded by 9 organisations from 6 NEA member countries, was established in 2013 with the aim of creating a database of thermodynamic data for advanced fuels, needed for a large spectrum of applications, from P&T in FBR to safety analysis (fuel cladding interaction, corium behaviour, etc.). The current version of the database contains a large set of binary and ternary systems for materials encountered for the purposes of fabrication and safety analyses:

- Fuels: oxide, nitride, carbide, metal fuels, oxide fuels with thorium, oxide and metal fuels with minor actinides;
- Fission products: Lanthanides (Ce, La, Gd, Nd), Metals (Pd, Ru, Rh, Te), Volatiles (Cs, Te, I, Ru), Grey phases (Ba, Sr, Mo, Zr);
- Cladding: Zircaloy, SiC, ODS steels, advanced cladding materials;
- Structural/control materials: concrete, vessel, control rods.

4. Liquid Metal Technologies

Following the publication of the second edition of the handbook on lead–bismuth eutectic alloys and lead properties, materials, compatibility, thermohydraulics and technologies [5], the expert group has re-discussed its scope and future related activities to include liquid Na activities the program of work which will aim at assessing available data to application in design, construction and licensing issues on the one hand and operation, In-Service Inspection, handling and maintenance on the other hand. Ongoing activities include a survey on data management requirements, the study of the effects of environment on the material behaviour and the chemistry of coolants and cover gas issues.

In addition, the NEA has also launched a benchmark on thermal-hydraulic safety issues of lead alloy cooled advanced nuclear energy systems (LACANES). This benchmark focuses mainly on characterizing the thermal hydraulic behaviour of such systems under the steady-state forced or under natural convection, which is of critical importance for system design development. The first phase of the characterization of the system and study of the steady-state forced case has now been completed [6]. Understandable guidelines for prediction pressure loss were obtained based on comparison between many predictions calculated by handbook correlations or CFD simulations. From these activities, a better understanding of pressure loss modelling in lead alloy cooled systems was obtained. The LACANES benchmark Phase-II in the case of natural circulation is now completed and the report should be published later this year.

5. Recycling technologies

There has been international interest in technologies and strategies to be deployed to minimize wastes and a wide consensus has emerged to prove the advantages of the approach based on fast reactors. The existing technologies and significant operational experience gained in the treatment of spent fuels from thermal power reactors are a good starting point for new recycling technologies but need to be adjusted to the specifics of fast reactor fuels. Fuel transuranic recycling will become a mandatory feature to pursue resource sustainability and waste minimization. The NEA Expert Group on Fuel Recycling Chemistry (EGFRC) is focusing on recycling technologies for spent nuclear fuel including waste treatment. An international review of separation processes has been performed, in applications related to the current and future nuclear fuel cycles along with recommendations for collaborative international efforts to further processes development. The study involves the assessment of separation processes, in particular separation of minor actinides and for different fuel cycle scenarios (including fast reactors) and the technology readiness levels. The state-of-the art report should be published later this year [7].

6. Partitioning and transmutation (P&T)

Alternative technologies to decrease the amount of high level radioactive waste to be stored in deep geological repositories are being developed, such as P&T using either critical or subcritical fast reactor systems. The development of P&T technology has the potential of minor actinides separation using either aqueous and pyroprocessing, demonstrating high separation factors at laboratory scale. In order to give experts a forum to present and discuss state-of-the-art developments in the P&T field, the NEA has been organizing biennial information exchange meetings on actinide and fission product partitioning and transmutation since 1990. The meetings covered scientific, as well as strategic/policy developments in the field of P&T, such as fuel cycle strategies and transition scenarios, radioactive waste management strategies (including secondary wastes), progress in fuels and materials, related physics and experiments, system design and economics of P&T. The last NEA Information Meeting on Actinide and Fission Product Partitioning and Transmutation was held in the San Diego (US) where more of 100 papers were presented covering all aspects of P&T (fuels, scenarios, advanced recycling, waste management)

7. Conclusions

Advanced nuclear systems and associated fuel cycles will address the major challenges facing the long term development of nuclear energy: competitiveness, meeting increasingly stringent safety requirements, sustainability, and waste management. A necessary condition for successful near and mid-term deployment of fast reactors and the associated fuel cycles is the understanding and assessment of technological and design options, based on past knowledge and experience, and on research and technology development efforts. Numerous and ambitious R&D programmes have been undertaken at the national level in many countries and in the framework of several international projects. The NEA will continue to support member countries in the field of fast reactor development and related advanced fuel cycles by providing a forum for exchange of information and various other collaborative activities.

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