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Basic research in support of innovative fuels design for the GEn IV systems: The F-BRIDGE project

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1. Summary and key messages

This paper gives an overview of the objectives and the structure of the F-BRIDGE European project as presented at the FISA conference in 2009 one year after its beginning. A quick presentation of the scientific results of the first year is also given. The F-BRIDGE project[1], which stands for "Basic Research in support of Innovative Fuels Design for the GEn IV systems", started in 2008 and will last four years. It seeks to bridge the gap between basic research and technological applications for generation IV nuclear reactor systems.

Up to now fuel development and qualification has been a successful but long and expensive process essentially based on an empirical approach. One of the challenges for the next generation of reactors is to significantly increase the efficiency in designing innovative fuels. The object of the F-BRIDGE project is to complement this empirical approach by a physically based description of fuel and cladding materials to enable a rationalization of the design process and a better selection of promising fuel systems. Advanced modelling and separate effects experiments are carried out in order to obtain more exact physical descriptions of ceramic fuels and cladding, at relevant scales from the atomic to the macroscopic scale. Research is also focused on assessing and improving 'sphere-pac' fuel, a composite-ceramics concept which has shown promise.

The project activities can be broken down into four main areas:

- Basic research investigations using a multi-scale approach in both experimentation and modelling to enable the generation of missing basic data, the identification of relevant mechanisms and the development of appropriate models.
- Transfer between technological issues and basic research by bringing together within the same project materials scientists, engineers and end-users.
- Assessment of the drawbacks and benefits of the sphere-pac fuel application to various Generation IV systems.
- Education and training to promote research in the field of fuel materials, to ensure the exchange of results and ideas among the participants and to link the project with other related European or international initiatives.

To reach its ambitious objectives, the project has at its disposal a 10.2 M€ budget including a 5.45 M€ EU contribution. It also relies on the excellence and complementary expertise of 19 partners: nuclear and non nuclear research organisations, universities, a nuclear engineering company, as well as technology and project management consultancy small and medium enterprises (SMEs).

During the first year of the project, several significant scientific objectives have been reached, in particular:

- successful high temperature electrical conductivity and oxygen diffusion measurements in uranium dioxide,
- a new thermodynamics assessment of the U–Pu–C system,
- the assessment of atomic scale methodologies for the description of actinide compounds,
- studies of the interaction between fuel and potential interstitial materials as a first step towards the evaluation of advanced sphere-pac fuel performance.

Another important achievement of this first year was the constitution and first meeting of the project user group. This group, which comprises six representatives from the European industry, utilities as well as manufacturers, is an important asset to the project

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[1] www.f-bridge.eu.

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to strengthen the links between basic research and technological issues.

2. Introduction

The sustainability and safety demands for nuclear energy have led the Generation IV international forum (GIF) to define requirements for the next generation of nuclear power plants[2]. The EU joined this effort and is part of the GIF initiative. In addition, the European sustainable nuclear energy technology platform (SNETP), which aims at coordinating research, development, demonstration and deployment (RDD&D) in the field of nuclear fission energy and gathers stakeholders from industry and research organisations, was officially launched in 2007. The vision report[3] of the SNETP reflects a consensus on the priorities of RDD&D in the field of nuclear fission, addressing the renaissance of nuclear energy with the deployment of Generation III reactors, and the development of Generation IV systems. To achieve its objectives, the SNETP has elaborated a strategic research agenda (SRA[4]), which identifies and prioritises the research topics and has been made available for public review before final publication.

Among the many aspects that need to be addressed, significant innovation is necessary to design fuel-cladding systems that contribute to meeting the Generation IV requirements. Support is allocated to these efforts throughout the world (Asia, United States...). In this field of major importance for its energy policy, the European Union needs to keep a leading position by contributing to select, define and manufacture fuel systems for the next generation of nuclear power.

Up to now fuel development and qualification has been a successful but long and expensive process essentially based on an empirical approach. European experts currently have an adequate knowledge of conventional fuel manufacturing and its behaviour under operating conditions encountered over the 50 years period of industrial application and R&D activities. This knowledge is embedded in current design and fuel performance modelling codes and has yielded promising concepts. In particular, composite ceramic fuels and among them "sphere-pac fuels" obtained by sol–gel fabrication and vibrational compaction techniques have been developed. Further investigation of these fuel concepts has been proposed because they exhibit significant advantages for Generation IV prerequisites such as actinide recycling and high burn-ups.

To significantly improve the efficiency of present fuels and design innovative fuel systems, however, the empirical approach has reached its limit. In many respects the understanding of fuels remains empirical, and cannot be easily extrapolated to new materials, new environments, or new operating conditions because the basic underlying mechanisms governing manufacturing, behaviour and performance remain poorly understood. One of the challenges is to significantly increase the efficiency in designing innovative fuels to both improve present fuel systems and design tomorrow's ones by complementing the empirical approach by a sounder physical description of fuel and cladding materials.

To do so, the *F*-BRIDGE project, which stands for **B**asic **R**esearch for **I**nnovative ***F***uels **D**esign for **GE**N IV systems, intends to develop an approach to fuel development based on a fundamental understanding of fuel behaviour from the atomic to the macroscopic scale and will apply it to fuel design and in particular to the improvement of the sphere-pac concept which exhibits significant advantages for Generation IV. This approach aims at a rationalization of the design process, a better selection of promising fuel systems, and therefore at a significant reduction of the time and costs currently required for developing new fuels. It also aims at contributing to the improvement of safety features of new systems under all operational and accidental conditions. This project has been proposed and accepted in 2008 within the framework of the Euratom FP7 Work Program[5]. Its full cost is 10.2 M€ including a 5.45 M€ EU contribution.

The breakthrough needed in fuel design can be achieved by using basic research investigations which enable the generation of missing basic data, the identification of relevant mechanisms and the development of appropriate models. Moreover, basic research brings further insight into the knowledge of the physical, chemical, and mechanical behaviour of fuel materials under extreme conditions of temperature and radiation, basic phenomena involved being de-correlated and studied at a relevant level of detail. In particular, a multi-scale approach in both experimentation and modelling is needed to reach a correct description of the phenomena involved. This is now possible because atomic scale experimental characterisation and modelling techniques have reached sufficient maturity to do so. There is, however, still a strong effort to be done to adapt these modelling and experimental tools and develop new methodologies best suited to fuel materials study. Furthermore, the key to successful multi-scale modelling is the effective translation and transfer of quantitative and qualitative information from one scale to another. Bridging the gaps in the multi-scale chain is necessary to improve the understanding and is expected to provide a solid basis for fuel performance codes to both enhance the sustainability of current fuel systems, and effectively develop innovative fuel systems within the Generation IV framework.

To be really effective and tackle the most important issues relative to the various advanced nuclear systems considered (light water reactors, sodium fast reactors, gas fast reactors, high temperature reactors...), basic research investigations must also be strongly connected to their clients, i.e. fuel designers and manufacturers. The transfer between technological issues and basic research can be effectively achieved by bringing together within the same project, as is the case in F-BRIDGE, materials scientists and engineers who have a detailed knowledge of critical issues. These experts working together ensure the integration of basic research results, leading to a direct impact and feedback on innovative fuel design, manufacturing, in pile behaviour prediction, and the optimisation of irradiation experiments. The translation of the technological issues into basic research items and of basic research results into useable qualitative and quantitative information is another key aspect. This requires an effort from all participants to look beyond the scope of their line of work. This is addressed by internal educational programmes and open inter-disciplinary discussions, ensuring mutual understanding and establishing a common vocabulary on the approach and issues the different disciplines are facing. Such an integration effort will eventually, without any doubt, build a bridge from basic research to technological applications for Generation IV fuel systems and in particular "sphere-pac" fuels as presented in Fig. 1.

3. Nature and scope of the project

3.1. General description of the project

The project activities have been organised in four domains as presented in Fig. 2:

[2] "A Technology Roadmap for the Generation IV Nuclear Energy Systems": http://gif.inel.gov/roadmap/.

[3] "The vision report of the SNETP": http://www.snetp.eu/home/liblocal/docs/snetp_vision_report_eur22842_en.pdf.

[4] "SNETP Strategic Research Agenda": http://www.snetp.eu/home/liblocal/docs/SRA_FinalDraft_Feb09.pdf.

[5] FP7 Euratom Work Program 2008/Area: Advanced Nuclear Systems/Topic: fission -2007-2.2.1: innovative fuels and claddings for generation IV systems.

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