IAEA Activities in the Area of Nuclear Power Reactor Fuel Engineering

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Abstract. The main IAEA program implementation tools in the area of fuel engineering are Coordinated Research Projects (CRP), Technical Meetings (TM), Expert Reviews, and NEA-IAEA International Fuel Performance Experiments (IFPE) Database. This report provides information about organization and implementation practices of these activities, and summarizes their major outputs including ongoing CRPs in the area of Fuel Engineering. The first announcement and preliminary information on the new CRP "Fuel Materials for Fast Rectors" to be launched in 2018 will be presented, including main topics for International collaboration within the CRP.

Key Words: The IAEA sub-programme on Nuclear Power Reactor Fuel Engineering, Coordinated Research Projects.

1. The IAEA subprogramme on Nuclear Power Reactor Fuel Engineering

While adhering to appropriate safety margins, effective design and manufacturing technologies, and optimized in-pile fuel performance are required to ensure reliability and economic efficiency in nuclear fuel utilization. To support this, the IAEA sub-programme on Nuclear Power Reactor Fuel Engineering assists interested Member States in organizing an adequate R&D programme by transferring information and sharing experiences. The sub-programme covers the following topics of expertise:

- Development, design and engineering;
- Fabrication: manufacturing techniques, nuclear safety and radiation protection in fuel fabrication;
- Behaviour, analysis and modelling:
    - behaviour during normal and overpower operation;
    - behaviour under postulated and severe accident conditions;
    - properties of zirconium alloys and other core materials relevant to performance;
    - corrosion and hydrogen effects;
    - post-irradiation examination;
    - inspection, reconstitution and repair; and
    - relationship with back-end requirements.
- Utilization and management;
- MOX, alternative fuels and advanced fuel technologies and materials;
- Economic and other aspects, e.g. environmental issues;
- Quality assurance and control.

In order to assist Member States in planning for and using nuclear science and technology for peaceful purposes, the International Atomic Energy Agency (IAEA) plans, implements and manages Coordinated Research Projects (CRPs), which are essential for the IAEA to foster collaboration between Member States and improve nuclear techniques worldwide.

A coordinated research project (CRP) is designed to encourage the acquisition and dissemination of new knowledge from the use of nuclear technologies and isotopic techniques. By bringing together research institutions in both developing and developed countries and sharing resources and expertise, CRPs help foster the exchange of scientific and technical information while achieving a particular research agenda. This also helps improve capacity building in Member States, which is especially important for developing countries that would otherwise be unable to undergo such extensive research projects.

Several examples of CRPs currently supported by the IAEA subprogramme on Nuclear Power Reactor Fuel Engineering are presented below.

2. CRP T12028 on Fuel Modelling for Accident Conditions (FUMAC)

Summary

The CRP supports the Member States in their efforts to analyse and better understand the behaviour of water-cooled power reactor fuel in accident conditions through sharing of experimental data and best practices in application of fuel modelling computer codes.

Background Situation Analysis

Fuel modelling is a recurrent priority in the IAEA sub-programme "Nuclear Power Reactor Fuel Engineering". Development and verification of computer codes are possible only on the basis of good experimental data that requires very durable and expensive in-reactor and post-irradiation studies. That is why international cooperation in this area is highly desirable, and the IAEA traditionally supports interested Member States in their efforts to enhance capacities of their computer codes used for prediction of fuel behaviour. Since the early nineties a series of four CRPs D-COM (1982-1984), FUMEX (1993-1996), FUMEX-2 (2002-2007) and FUMEX-3 (2008-2012) targeted fuel modelling in normal operational conditions. Those projects were highly appreciated by Member States, and the proposed CRP "Fuel Modelling in Accident Conditions" (FUMAC) continues the series with the focus on fuel behaviour in design basis and severe accidents that is particularly demanding nowadays.

CRP FUMAC is planned under the IAEA Nuclear Safety Action Plan with the well-proven organizational approach used in the CRP FUMEX-3, which presumes cross-comparisons of computer codes used in different Member States and close collaboration with the NEA/OECD and the joint NEA-IAEA International Fuel Performance Experimental (IFPE) Database. Selected sets of accident simulation experimental results, provided by CRP members, will be integrated into the IFPE Database and used for codes verification.

In the light of the Fukushima accident, the 2012 meeting of the IAEA Technical Working Group on Fuel Performance and Technology approved FUMEX-3 results and recommended IAEA to launch a new fuel modelling CRP FUMAC focusing on accident conditions. Preliminary ideas of FUMAC were initiated at the Technical Meeting "Fuel Behaviour and Modelling under Severe Transient and Loss of Coolant Accident (LOCA) conditions" in Japan in October 2011 and agreed with NEA/OECD in 2012, with more detailed discussion on its objectives at the Technical Meeting "Modelling of Water-cooled Fuel Including Design Basis and Severe Accidents" in China and the 20^{th} International QUENCH Workshop in Germany in 2013.

Participants: 24 organizations from 18 countries (+ 2 observers)

Planned duration: 2014-2017

- The first Research Coordination Meeting (RCM) was held from 11 to 14 November 2014 in Karlsruhe;
- The second RCM was held from May 30 to June 2, 2016 in Vienna;
- The third RCM is planned to be held in November 2017.

CRP Overall Objectives

Better understanding and enhanced safety of nuclear fuel behaviour in accident conditions.

Nuclear Component

Nearly the entire hazard from an accident at a nuclear reactor stems from the nuclear fuel. Computer modelling allows the prediction of the key aspects of the performance of fuel materials and components (temperatures, dimensional changes of fuel components, release of fission gases, etc.), and the development of acceptable safety limits of operational parameters. The subject of CRP FUMAC fully corresponds to the aim of the IAEA Nuclear Safety Action Plan at enhancing safety of nuclear reactor operations.

3. CRP T12030 on Analysis of Options and Experimental Examination of Fuels for Water-Cooled Reactors with Increased Accident Tolerance (ACTOF)

Summary

Nuclear fuel is a highly complex material that has been subject to continuous development over the past 40 years and has reached a stage of development where it can be safely and reliably irradiated up to 65 GWd/tU or more in commercial nuclear reactors. During this time there have been many improvements to the original designs and materials used. However, the basic design of uranium oxide fuel pellets clad with zirconium alloy tubing has remained the fuel of choice for the vast majority of commercial nuclear power plants.

Severe accidents, such as those at Three Mile Island and Fukushima Daiichi have shown that under such extreme conditions, nuclear fuel will fail and the high temperature reactions between zirconium alloys and water will lead to the generation of hydrogen with the potential for explosions to occur, damaging the plant further.

Recognizing that the current fuel designs are vulnerable to severe accident conditions, there is renewed interest in alternative fuel designs that would be more resistant to fuel failure and hydrogen production. Such new fuel designs would need to be compatible with existing fuel and reactor systems if they are to be utilized in the current reactor fleet and in current new build designs, but there is also the possibility of new designs for new reactor systems.

Globally, there is a great deal of experience with the performance of reactor fuel in off-normal conditions. Theoretical studies and experiments have been performed and there have been excursions from normal operating conditions in a few power reactors. During such an excursion, the difference between an incident of limited or no consequence and a severe accident, such the one at Fukushima, depends on the conditions in the reactor and the performance of the fuel under those conditions. The CRP T12030 "Analysis of Options and Experimental Examination of Fuels for Water-Cooled Reactors with Increased Accident Tolerance" (ACTOF) explores the potential to design and operate advanced fuel types that are intended to be more tolerant of severe accident conditions whilst retaining the capability of current fuel designs for safe operation under normal operation and anticipated transient conditions.

Participants: 14 organizations from 11 countries and 1 observer.

Planned duration: 2015-2018

- The first RCM was held from 2 to 4 November 2015 in Vienna (12 participants from 11 Member States and 1 observer from OECD-NEA);
- The second RCM was held from 20 to 22 June 2017 in Vienna;

Main objective

To support options for the development of nuclear fuel with an improved tolerance of severe accident conditions:

- To acquire data through experiments on new fuel types and cladding materials to support their use for fuel with improved accident tolerance;
- Support modelling of new fuel designs with advanced cladding or fuel.

Expected Outcomes

- Provision of information to Member States to support decision making on the choices available to improve the safety of Nuclear Power Plants under severe accident conditions
- Provision of data, analyses and advanced techniques to understand and predict the behaviour of the components and the integral performance of accident tolerant fuel designs under normal and transient conditions.

Expected Results

- Well checked experimental data on the behaviour of candidate materials for Accident Tolerant Fuel designs;
- New models of materials behaviour in fuel modelling codes;
- Results of computer modelling of advanced fuel types under normal and accident conditions.

4. CRP T14003 on Accelerator Simulation and Theoretical Modelling of Radiation Effects-II (SMoRE-II)

Summary

The development of structural materials for advanced reactor concepts and life extension of existing reactors require a new paradigm for irradiation testing. This new paradigm is accelerator-based ion (electron, proton, heavy ion) irradiation, which allows accumulation of high radiation damage within a reasonable time, compared with extremely long experiments in research reactors. Establishment of its efficacy will be accomplished through the use of standardized testing to establish confidence in the results of ion irradiation generated in different laboratories and to verify agreement between neutron- and ion-irradiated property-controlling microstructures. Several important questions regarding the behaviour of irradiated materials will be addressed, including: understanding the dose-rate effect of ion irradiations compared to neutron irradiations; understanding the primary damage state of materials under different irradiation conditions; effects of very high dose/high-temperature ion irradiations for future reactor applications; and the investigation of microstructure changes during the incubation period (e.g., of void swelling). Ultimately, the determination of best practices and criteria for comparison of ion and neutron irradiations will be made.

Background Situation Analysis

Several innovative reactor designs have been proposed for future nuclear energy systems (e.g. Gen IV, INPRO, ADS, ITER), having several advantages; e.g., enhanced sustainability, reduced radioactive waste, enhanced safety, improved economics for electricity production, production of process heat or hydrogen, and increased proliferation resistance. The operating regime for structural materials in new reactor concepts extends to higher temperatures and doses and takes place in more aggressive environments than in existing power reactors. Additionally, life extension of existing water reactors will be critical in filling the time gap until the implementation of advanced designs.

The lack of appropriate test reactors, the cost and the length of time needed to conduct a neutron irradiation campaign on promising new materials are incongruent with the timescale for new reactor implementation. Therefore, more expedient means must be found to develop new materials. The most promising avenue is the use of ion irradiation to emulate the property-controlling microstructures created in reactor. To validate the capability of ion irradiation to emulate reactor irradiation, a set of best practices for conducting ion irradiations for use in the design of new materials for existing and future reactors must be developed.

To achieve these objectives, research programs and information exchange are both needed to develop and qualify new materials for key structural components. An international collaboration must be organized, for which IAEA is the natural umbrella agency; no single laboratory is capable of achieving the goal of this project.

Participants: 17 organizations from 11 countries.

Planned duration: 2016-2019.

- The first RCM was held from 27 to 30 March 2017 in Vienna.

CRP Overall Objective

Development of best practices for conducting ion irradiations for the design of new materials for existing and future reactors.

Specific Research Objectives

- Fabrication and distribution of samples of selected materials for ion irradiation and post-irradiation examination;
- Intercomparison of results of ion irradiations across the CRP and the development of recommendations on improved best practices.

Expected Research Outputs

- Reports on the intercomparison of ion irradiation of selected samples, provided by CRP members, between laboratories;
- Recommendations for best practices for ion irradiation for the emulation of in-reactor damage in structural materials.

CRP Expected Research Outcomes

- Quantification of the degree of agreement between microstructures generated by ion and neutron irradiation;
- Enhanced confidence in ion irradiation as a reliable technique for screening materials for future reactors by reducing interlaboratory variability.

Nuclear Component

- Development of new materials for advanced and innovative nuclear reactors, investigation of properties of structural materials in high-radiation environments, fundamental understanding of the nature of radiation damage, sharing of best practices for ion beam irradiation for materials testing.

5. New CRP on Fuel Materials for Fast Reactors

A new CRP on Fuel Materials for Fast Reactors is planned to be launched in 2018. A CRP begins when a scientific panel of experts proposes a research theme that stimulates and coordinates the undertaking of research by both scientists in the IAEA and different research institutions in Member States. There is then a call for project proposals and when the selection is completed, the IAEA Project Officer will then liaise with Chief Scientific Investigators from the different research institutions involved in order to develop and manage the research programme, which normally has duration of between 3 and 5 years.

Main objective

Bringing together specialists from the Member States with active fast reactor programs for a coordinated support of their national efforts in the R&D areas:

- traditional (MOX) and innovative "dense” non-oxide fuels, including ceramic (carbides and nitrides) and metallic (U-Pu alloys) fuels;
- thermo-mechanical properties and irradiation behaviour of fuel cladding materials (austenitic, ferritic-martensitic, high-nickel alloys, ODS steels);
- compatibility of stainless steels with heavy liquid metals (also for ADS);
- validation, verification and benchmarking of FR fuel performance codes.

A preliminary discussion on the scope and objectives of the new CRP is foreseen to take place during the International Conference on Fast Reactors and Related Fuel Cycles: Next Generation Nuclear Systems for Sustainable Development (FR17).