FUEL RESEARCH FOR SUBCRITICAL AND CRITICAL GEN-IV SYSTEMS COOLED BY HEAVY LIQUID METAL

Background

The participation of SCK•CEN in the worldwide GEN-IV research can be considered as an opportunity. Today's GEN-IV research at SCK•CEN is mainly driven by the interests of the project MYRRHA (Multipurpose hYbrid Research Reactor for High-tech Applications). The main goal of this project is to build at SCK•CEN in Mol a new generation fast spectrum, subcritical, research and materials testing reactor MYRRHA driven by a high-energy proton accelerator. This GEN-IV MTR is cooled by heavy liquid metal (Pb-Bi) and will be used for the ADS concept demonstration, testing and qualification of new fuels, transmutation targets and innovative materials. On the European scale, MYRRHA is integrated in the Euratom FP6 Integrated Project (IP) EUROTRANS (EUROpean research programme for TRANSmutation of high level nuclear waste in an accelerator driven system), as the small-scale experimental machine for transmutation demonstration called XT-ADS. Last but not least, this experimental facility will also demonstrate the technological feasibility of the LFR (Lead-cooled Fast Reactor) GEN-IV concept; in EU the LFR design studies are performed in the framework of the Euratom FP6 ELSY (European Lead-cooled SYstem) project, where SCK•CEN is a partner.
Among the research needed to ensure a safe and reliable operation of the MYRRHA/XT ADS reactor, the development and qualification of fuel and cladding materials have been recognized as one of the main key issues to be addressed.

Objectives

The fuel research domain of GEN-IV as a whole is obviously too vast for SCK•CEN, and priorities have to be defined. Four scopes were identified in the GEN-IV fuel R&D that could be covered by the Institute for Nuclear Materials Science:

1. Research and conceptual design of demonstration experiments ("proof-of-principle") for MYRRHA/XT ADS driver fuel;
2. The MYRRHA/XT ADS driver fuel development, fabrication, qualification and licensing;
3. Research on advanced fuels and targets dedicated to the transmutation of the minor actinides (MA) in MYRRHA /XT and other ADS and in the GEN-IV reactors;
4. GEN-IV fuel research in a broader context (LFR, SFR, GFR, …).

R&D for the MYRRHA/XT ADS driver fuel demonstration and development (items 1 and 2) are of the highest priority. Highly enriched PuO_2/UO_2 MOX (30-35 wt% of RG Pu in HM) as the fuel and the cladding made of advanced ferrite-martensitic steel (FMS) T91mod and austenitic stainless-steel (ASS) AIM1 are proposed to use for the fuel element fabrication. In spite of a large database existing in USA, France and Japan on qualification of the fuel rods with the highly enriched MOX and claddings made of ASS, 316SS, D9, AIM1 and of FMS HT-9, EM10 in the typical environment of a fast reactor cooled by liquid sodium up to burnup of 140-200 MWd/kg-HM, the compatibility of the system "MOX-T91mod/AIM1-PbBi" has still to be tested under conditions (temperature range, neutron flux, spectrum and doses) representative for MYRRHA/XT ADS.
The second priority concerns the special fuel dedicated to the MA transmutation in the GEN-IV reactors (including ADS) (item 3). The main goal here is to collect and develop the database of properties and models for these dedicated fuels, to design fuel elements for future GEN-IV transmuters and to simulate their performances. These studies are mainly performed in the frameworks of the Euratom FP6 IP EUROTRANS, ACTINET Network, OECD/NEA international programmes and are considered as underlying long-term research. Studies in item 4 are performed only if they are useful for items 1-3, as it is in the case of the Euratom FP6 Project ELSY.

Principal results

The conceptual design of the MYRRHA first core, completed in 2004, was significantly updated. A detailed design is under way now. A large part of this work is performed in the framework of the FP6 IP EUROTRANS, which is progressing accordingly and has to be completed in 2009. A large volume of research was performed for the preparation of the properties database for MOX fuel, cladding materials and Pb-Bi(e) coolant, for the completing of the preliminary design of the MYRRHA/XT ADS fuel rod, fuel assembly and core, for the development/updating of the relevant fuel performance codes, and for the preliminary formulation of the fuel fabrication specifications and of a program for fuel demonstration. (A part of the MYRRHA properties database was included in the OECD/NEA "Handbook on Lead-bismuth Eutectic Alloy and Lead Properties, Materials Compatibility, Thermal Hydraulics and Technologies").

The developed database was installed in the modified at SCK•CEN fuel performance code FEMAXI used for preliminary modelling of the MYRRHA/XT ADS driver fuel and in the SCK•CEN code MACROS devoted to the detailed analysis of the long-term behaviour of mixed actinide oxide fuel (MOX and inert matrix fuel containing MA). Safety analysis of the fuel elements behaviour under ULOF (Unprotected Loss-Of-Flow) and UTOP (Unprotected Transient of Over-Power) design extended conditions was also performed. The preliminary design of the driver fuel elements of the MYRRHA/XT ADS, proposed on the early stage of the project, has been significantly improved on the basis of the results obtained in the modelling. The acquired experience and knowledge was also used in the fuel pre-design for ELSY GEN-IV reactor.

Fuel elements with the uranium free inert matrix (MgO and Mo) fuels containing MA were also designed and modelled to study their behaviour and efficiency of MA burning in MYRRHA/XT ADS and in EFIT (European Facility for Industrial scale Transmutation). The last is performed in the framework of the IP EUROTRANS.

Future developments

The work on the MYRRHA/XT-ADS driver fuel development and licensing is still at the beginning. The first steps were taken in this direction in 2002-2004 (Contract with BN, Contacts with Russian research centers and BOR-60, creating MAF task force to start preparation of documents for licensing). However, financial and man-power limitations did not allow at this time to advance substantially in this direction. The following actions, related to the detailed design, driver fuel development and licensing, should be lunched very soon:

- Analysis of the problems of the development and fabrication of the driver fuel for the MYRRHA/XT ADS;
- The development of the specifications for the driver fuel rod production;
- The development of the R&D programme for the demonstration and qualification of the driver fuel pin and a fuel assembly;
- The preliminary analysis of licensing problems of the MYRRHA XT-ADS;
- Updating and issue of the fast spectrum version of the MACROS code capable to deal with the highly enriched MOX and IMF (CERCER and CERMET) containing a large amount of MA;
- Mechanistic modelling of high-burnup effects and individual processes in the MOX and innovative fuels.

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