NEUTRONIC DESIGN OF THE XT-ADS CORE

Background

The EUROTRANS project is an integrated project in the 6th European Framework Program in the context of Partitioning and Transmutation (P&T). The objective of this project is the step-wise approach to a European Transmutation Demonstration. This project aims to deliver an advanced design of a small-scale Accelerator Driven System (ADS), XT-ADS, as well as the conceptual design of a European Facility for Industrial Transmutation (EFIT). The partners of this project accepted to use the MYRRHA "Draft-2" design file as a starting basis for the design of the short-term XT-ADS demonstration machine. Instead of starting from a blank page, this allowed optimising an existing design towards the needs of XT-ADS, and this within the accepted limits of the safety requirements. Many options have been revisited and the framework is now set up.

Objectives

The main two objectives of the XT-ADS machine are the following: to demonstrate the feasibility of the ADS concept and to perform as a multi-purpose irradiation facility. Special attention is paid to the possibility of testing fuel dedicated to transmutation of minor actinides and long-life fission products. During the demonstration phase, the core will be loaded with MOX fuel in a "clean core" configuration. Since the XT-ADS must be a representative prototype, it has to operate at a reasonable power, a minimum of 50 MW_{th} was set in the objectives. After this phase, the core will house In-Pile-Sections of different types for irradiating material samples, new types of fuel pins. We aim to be able to provide irradiation conditions that are close to EFIT conditions so XT-ADS can be used as a test-bed for EFIT parts.

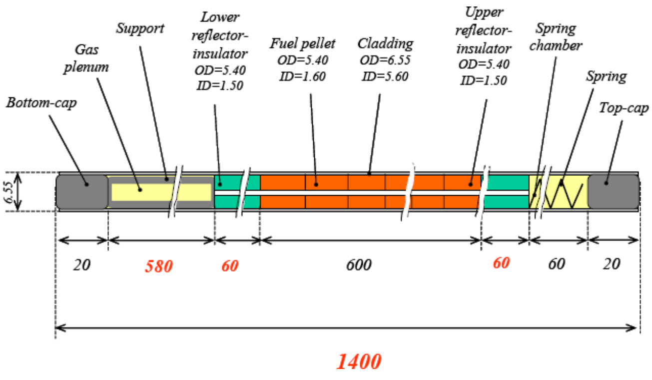
Principal results

Compared to the MYRRHA "Draft-2" design file, several parameters and boundary conditions have changed: 1) on the demand of the safety work package, the fuel power density was reduced from 1000 W/cm^3 to 700 W/cm^3; 2) the inlet and outlet temperature of the coolant are set to 300°C and 400°C respectively (compared to 200°C and 400°C) that avoids embrittlement of the T91 type steel used as structural material for the fuel.

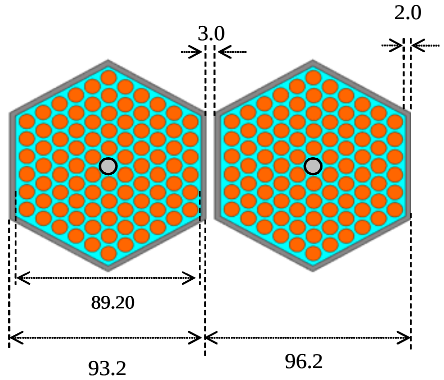
The so-called reactor-grade plutonium coming from the reprocessing of PWR spent fuel with an initial enrichment of 4.5% in uranium-235, a burn-up of 45 GWd/t and a cooling period of fifteen years is expected to be used for MOX fuel production. The plutonium content in heavy metal is about 30 wt%. In MYRRHA MOX fuel coming from less burnt uranium fuel was used and hence it had a better plutonium vector. The main motivation for the first choice was the fact that this type of plutonium vector will be easier to get hold of.

The fuel pin consists of a fuel pellet column of 60 cm with on both ends a neutron reflector made of yttria stabilized zirconium ceramics to increase the neutron economy, a fission gas plenum and closing caps. The fuel pellets are of the annular type to reduce the inner fuel temperature which gives larger margins to fuel melting in case of an accidental situation. The fuel rods are arranged in a hexagonal lattice of 91 positions of which the central position is reserved for measurement purposes (and hence contains no fissile material). The pins are placed with a larger pitch compared to MYRRHA in order to reduce the pressure drop over the core.

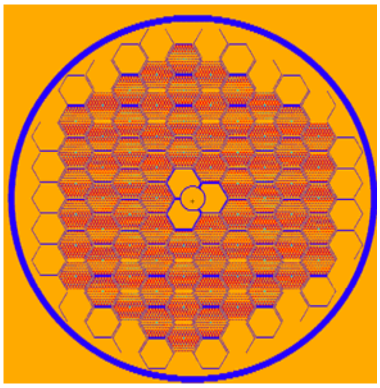
XT-ADS fuel pin



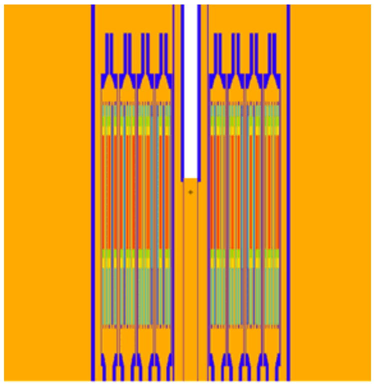
XT-ADS fuel assembly



The "clean" core configuration without In-Pile-Sections (IPS) and test assemblies has been defined containing 72 fuel assemblies in a symmetric arrangement around the three emptied positions to house the spallation target module. As a result of all the modifications (other plutonium vector, larger fuel pin pitch, larger assemblies and larger assembly pitch) the fuel density has been reduced significantly and hence the k_{eff} of the core decreased compared to MYRRHA. In order to reach again the target value of k_{eff} = 0.95, it was decided to increase the plutonium content of the MOX fuel.



The analysis of this clean core has been performed using the Monte-Carlo particle transport code MCNPX combined with the nuclear data from the JEFF 3.1 library. For a weight percentage of 31.5% of plutonium content, the computed k_{eff} value was 0.95324. The corresponding K_S is equal to 0.95711 which corresponds to a multiplication factor of 23.31. The source importance is $\varphi^* = 1.095$. With an accelerator beam of 600 MeV protons and a current of 2.33 mA, a core thermal power of 57 MW is reached. The neutron source intensity is about 15 neutrons per proton (which is significantly higher than in the MYRRHA case due to the higher proton energy used for XT-ADS). The maximal fast flux reached in the hottest fuel pin amounts to $0.72 \cdot 10^{15}$ n/(cm^2.s), while the maximal total flux reached in the hottest pin amounts to $3.31 \cdot 10^{15}$ n/(cm^2.s). These values are still open for optimisation since the optimal neutron source position still has to be assessed.



A preliminary thermo-hydraulic analysis showed that all temperatures stay well within limits for normal operations. The linear power produced in the hottest pin is only 221 W/cm (where in MYRRHA it was 350 W/cm). The critical issue here is the cladding integrity under accidental conditions. The combination of a rise in temperature for the T91 cladding and the built-up pressure by fission gas release in the gas plenum defines the time-to-failure of the cladding material. Simulations show that under an Unprotected-Loss-Of-Flow (ULOF) accident, the maximal T91 temperature is between 800°C and 850°C. In this temperature range cladding failure grace time becomes very dependent on fission gas pressure. In the first version of the XT-ADS fuel pin, the same fission gas plena were proposed as in MYRRHA. However, later analysis showed that a larger plenum is needed to assure acceptable grace times (~half hour) in the case of a Loss-Of-Flow accident at the End-Of-Fuel-Life if all accumulated fission gas will be released from the fuel. In order to cope with this issue, an enlarged fission gas plenum was proposed for XT-ADS indicated in the figure on the previous page.

In order to guarantee the safe operation during core reloading and reshuffling, a preliminary study was devoted to the design of a neutron absorber element with the same geometrical and material properties as the normal fuel assemblies. This allows the movement and core placement of these elements by means of the fuel handling machines and hence avoid an extra machine to be fitted in an already tight space.

Future work

Now the fuel pin and assembly geometry have been defined and the "clean" core configuration has been set, the study for the core loaded with In-Pile-Sections has started. A so-called Task Force has been set-up with partners from different tasks and work-packages (core design, target design, primary system design, safety) in order to improve the interaction between those fields.

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Main reference

D. De Bruyn, D. Maes, P. Schuurmans, G. Van den Eynde, H. Aït Abderrahim (2006) "Status of the ADS Research & Development and of the related technology in Belgium: the evolution of the MYRRHA project", IAEA Technical Meeting "Review of the Status of Accelerator Driven Systems R&D and Technology", Vienna (Austria), December 4-6, 2006