Contribution of the European Commission to a European Strategy for HLW Management through Partitioning and Transmutation: Presentation of MYRRHA and its Role in the European P&T Strategy

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Abstract

To be able to answer the world's increasing demand for energy, nuclear energy must be part of the energy mix. As a consequence of the nuclear electricity generation, high-level nuclear waste (HLW) is produced. The HLW is presently considered to be managed through its burying in geological storage. Partitioning and transmutation (P&T) has been pointed out as the strategy to reduce the radiological impact of HLW. Transmutation can be achieved in an efficient way in fast neutron spectrum facilities, both in critical fast reactors as well as in accelerator driven systems (ADSs).

For more than two decades, the European Commission has been co-funding various research and development projects conducted in many European research organisations and industries related to P&T as a complementary strategy for high-level waste management to the geological disposal. In 2005, a European strategy for the implementation of P&T for a large part of the HLW in Europe indicated the need for the demonstration of its feasibility at an 'engineering' level. The R&D activities of this strategy were arranged in four "building blocks":

1. *Demonstration of the capability to process a sizable amount of spent fuel from commercial light water reactors (LWRs) in order to separate plutonium, uranium and minor actinides.*
2. *Demonstration of the capability to fabricate at a semi-industrial level the dedicated fuel needed as load in a dedicated transmuter.*
3. *Design and construction of one or more dedicated transmuters.*
4. *Provision of a specific installation for processing of the dedicated fuel unloaded from the transmuter, which can be of a different type than the one used to process the original spent fuel unloaded from the commercial power plants, together with the fabrication of new dedicated fuel.*

MYRRHA contributes to the third building block. MYRRHA is an ADS under development at SCK•CEN in collaboration with a large number of European partners. One of the objectives of the new MYRRHA facility is to address the technical feasibility of transmutation of HLW. Within this paper the development of the MYRRHA project and its role as transmutation facility are described briefly.

Introduction

Presently, the EU relies on 30% of its electric power production from Generation II and III nuclear fission reactors leading to the annual production of 2 500 t/y of used fuel, containing 25 t of plutonium, and HLW such as 3.5 t of MAs, namely neptunium (Np), americium (Am) and curium (Cm), and 3 t of long-lived fission products (LLFPs). These MA and LLFP stocks need to be managed in an appropriate way. The used fuel reprocessing (closed fuel cycle) followed by the geological disposal or the direct geological disposal (open fuel cycle) are today the envisaged solutions, depending on national fuel cycle options and waste management policies. The required time scale for geological disposal exceeds our accumulated technological knowledge and this remains the main concern of the public. P&T has been pointed out in numerous studies as the strategy that can relax constraints on geological disposal, and reduce the monitoring period to technological and manageable time scales. Therefore, a special effort has to be made to integrate P&T in advanced fuel cycles and advanced options for HLW management. Transmutation based on critical or sub-critical fast spectrum transmuters should be evaluated in order to assess the technical and economic feasibility of this waste management option, which could ease the development of a deep geological storage.

Despite diverse strategies and policies pursued by European Member States concerning nuclear power generation and envisaged fuel cycle policy ranging from the once-through without reprocessing to the double-strata fuel cycle ending with the ADS as the ultimate burner or Generation IV fast critical reactors multi-recycling all transuranic materials, P&T requires an integrated effort at the European and even worldwide levels. Even when considering phasing out of nuclear energy, the combination of P&T and a dedicated burner such as ADS technologies, at a European scale, would allow meeting the objectives of both types of countries: the ones phasing out nuclear energy and countries favouring the continuation of nuclear energy development towards the deployment of new fast spectrum reactors.

After nearly 20 years of basic research funded by national programmes and Euratom Framework Programmes (FPs), the research community needs to reach a position of being able to quantify indicators for decision makers, such as the proportion of waste to be channelled to this mode of management, but also issues related to safety, radiation protection, transport, secondary waste streams, costs and scheduling. These elements must be delivered by the EU organisations working on P&T research, all largely involved in the various FP projects related to high-level waste management via P&T and acting from FP4 to FP7. A summary table (Table 1) indicates European Commission investment in P&T research through the Euratom FP. The funding of P&T projects highlighted does not always represent a full financial contribution to the P&T activity area and in itself shows the effort provided through the co-funding of P&T research activities by Euratom.

Table 1: Funding of partitioning and transmutation (P&T) activities in Euratom FPs

3rd EURATOM Programme on Management and Storage of HLW (1990–1994)	EURATOM FP4 (1994–1998)	EURATOM FP5 (1998–2002)	EURATOM FP6 (2002–2006)	EURATOM FP7 (2006–2012)
4.8 M€	5.8 M€	28 M€	31 M€	31 M€

From 2005, the research community on P&T within the EU started structuring its research towards a more integrated approach. This resulted during the FP6 in two large integrated projects, namely EUROPART dealing with partitioning, and EUROTRANS dealing with ADS design for transmutation, development of advanced fuel for transmutation, R&D activities related to heavy liquid metal (HLM) technology, innovative structural materials and nuclear data measurement. This approach resulted in a European strategy based on the so-called four building blocks at engineering level for P&T:

1. Demonstration of the capability to process a sizable amount of spent fuel from commercial LWRs in order to separate plutonium (Pu), uranium (U) and minor actinides (MA).
2. Demonstration of the capability to fabricate at a semi-industrial level the dedicated fuel needed to load in a dedicated transmuter.
3. Design and construction of one or more dedicated transmuters.
4. Provision of a specific installation for processing of the dedicated fuel unloaded from the transmuter, which can be of a different type than the one used to process the original spent fuel unloaded from the commercial power plants, together with the fabrication of new dedicated fuel.

This approach will result in the identification of the costs and the benefits of P&T for European society.

The MYRRHA project contributes heavily to the third building block of this European strategy and in this paper we will focus on the ADS programme in the EU through the MYRRHA project and the associated FP7 projects contributing to the progress of ADSs in Europe, namely:

- ARCAS project [1]: aiming at a technical and economical comparison of FRs and ADSs for transmutation of Mas.
- CDT project [2]: aiming at setting up a centralised multidisciplinary team based at the Belgian Mol site to obtain an advanced design of a flexible fast spectrum irradiation facility working in sub-critical mode (ADS) and critical mode by building up on what has been accomplished during the FP5 and FP6 projects related to ADS design and national programmes' projects related to MYRRHA.
- MARISA project: aiming at bringing the MYRRHA project to a level of maturity required to start the construction phase of the MYRRHA facility.
- MAX project [3]: aiming at consolidating the conceptual design of the superconducting linear accelerator for MYRRHA (MLA) with its reliability target as the principal focus, and at initiating the engineering design of selected components, preparing for adequate prototyping activities.
- FREYA [4] project: aiming at validating the methodology of online reactivity monitoring initiated within the GUINEVERE project [5] in FP6 and planned to be used in MYRRHA. The project is also intended to support the development of the core design and operation of MYRRHA.
- MAXSIMA project [6]: aiming at contributing to the safety assessment studies of MYRRHA.

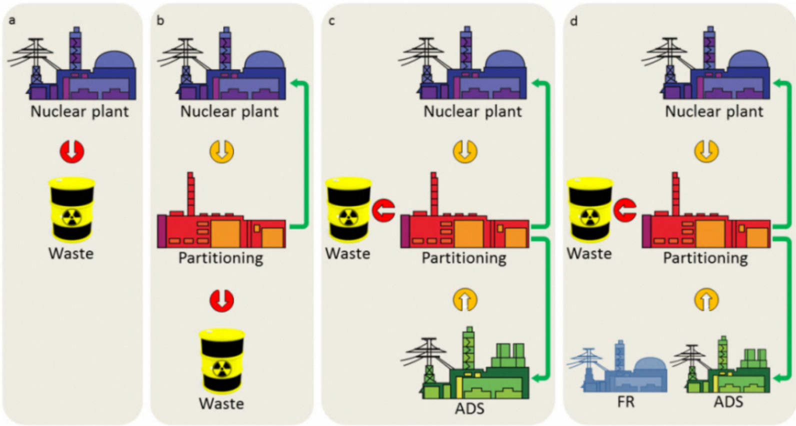
Partitioning and transmutation

The concept of P&T has three main goals: the reduction of the radiological hazard associated with spent fuel by reducing the inventory of MAs, the reduction of the time interval required to reach the radiotoxicity of natural uranium, and the reduction of the heat load of the HLW packages to be stored through geological disposal leading to its efficient use.

Partitioning is the separation of the radiotoxic elements out of spent fuel. Within the concept of P&T, one can distinguish the following possible fuel cycles, as seen in Figure 1:

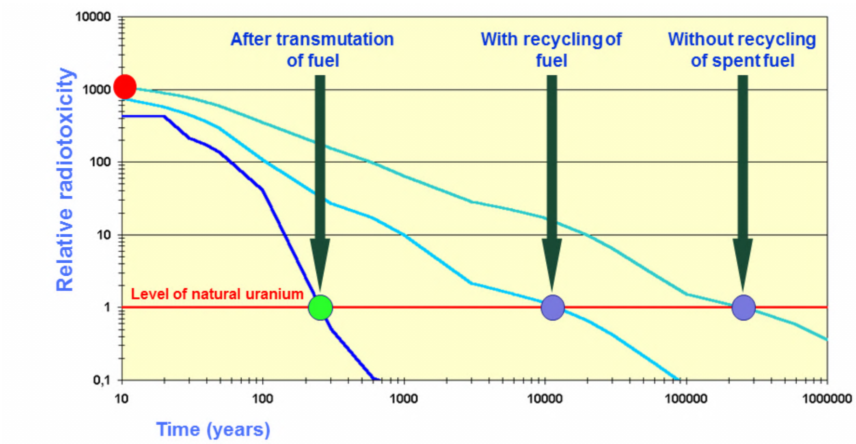
- in the "once-through" nuclear fuel cycle (a), there is no reprocessing of the spent fuel;
- within a simple recycle programme, a part of the plutonium is reused, together with fresh uranium, to produce mixed oxide (MOX) fuel (b);
- in a next step, the unprocessed actinides can be 'burned' in an ADS (c);
- in the double strata concept (d), fuels with a high content of MAs can be "burned" in ADSs or dedicated FRs.

Figure 1: Schematic overview of partitioning



Transmutation of minor actinides (like americium, neptunium and to a less extent curium) present in the nuclear waste reduces the radiological impact of the HLW and the needed legal monitoring periods to human periods to mitigate human ingress. The time scale needed for the radiotoxicity of the waste to drop to the level of natural uranium will be reduced from a "geological" value (500 000 to 1 million years) to a value that is comparable to that of human activities (several hundreds of years) [7-9]. During transmutation, the nuclei of the actinides are fissioned into shorter-lived fission products (Figure 2).

Figure 2: Radiotoxicity of radioactive waste [10]



In order to transmute the MAs in an efficient way, high-intensity and high-energy neutron fluxes are necessary. Therefore, only nuclear fast fission reactors being critical or sub-critical can be utilised.

If the aim is to transmute large amounts of MAs in the dedicated transmuter then it is necessary to use an ADS. The sub-criticality is mandatory due to the smaller delayed neutron fraction within the MAs (0.01 to 0.1%) compared to uranium-235 (0.7%) to allow the criticality variation control when considering large inventory of MAs in the core (< 10%).

The implementation of P&T on a large part of the HLW in Europe needs the demonstration of its feasibility at an engineering level. MYRRHA will contribute to the demonstration for the engineering feasibility of the ADS concept and to the efficient demonstration of the transmutation within this concept. Nevertheless, MYRRHA has been conceived as a multi-purpose irradiation facility.

MYRRHA – A flexible fast spectrum irradiation facility

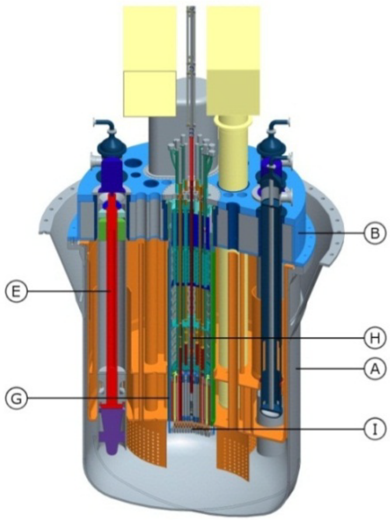
MYRRHA (Multi-purpose hYbrid Research Reactor for High-tech Applications) is the flexible experimental ADS in development at SCK•CEN. MYRRHA is able to work both in sub-critical (ADS) and in critical mode. In this way, MYRRHA should target the following applications:

- To demonstrate the ADS full concept by coupling the three components (accelerator, spallation target and sub-critical reactor) at reasonable power level to allow operation feedback, scalable to an industrial demonstrator.
- To allow the study of the efficient technological transmutation of HLW.
- To be operated as a flexible fast spectrum irradiation facility allowing for:
  - Fuel developments for innovative reactor systems.
  - Material developments for Gen IV systems and fusion reactors.
  - Radioisotope production for medical and industrial applications.
  - Industrial applications, such as Si-doping.

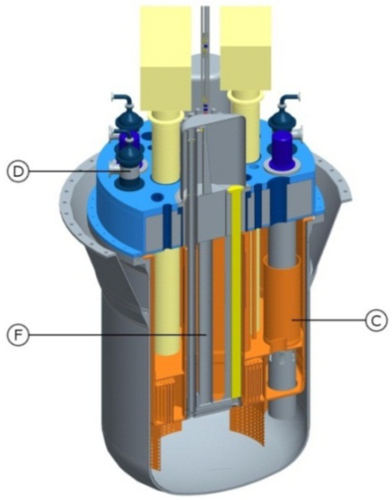
In ADS mode, the linear accelerator is the driver of MYRRHA while it provides the high energy protons that are used in the spallation target to create primary neutrons which in turn feed the subcritical core. The accelerator must be able to provide a proton beam with energy of 600 MeV and a maximum current of 4 mA, which will be delivered to the core in continuous wave mode. The beam is delivered to the core from above through a window-target design.

MYRRHA is a pool-type ADS; the reactor vessel houses all the primary systems. In the current design (Figure 3), the reactor pit implements the function of secondary containment in case the reactor vessel leaks or breaks, improving the capabilities of the reactor vault air cooling system. The vessel is closed by the reactor cover, which supports all the in-vessel components. A diaphragm inside the vessel functions to separate the hot and cold lead–bismuth eutectic (LBE), to support the in-vessel fuel storage and to provide a pressure separation. The core is held in place by the core support structure consisting of a core barrel and a core support plate.

Figure 3: Section of the MYRRHA reactor

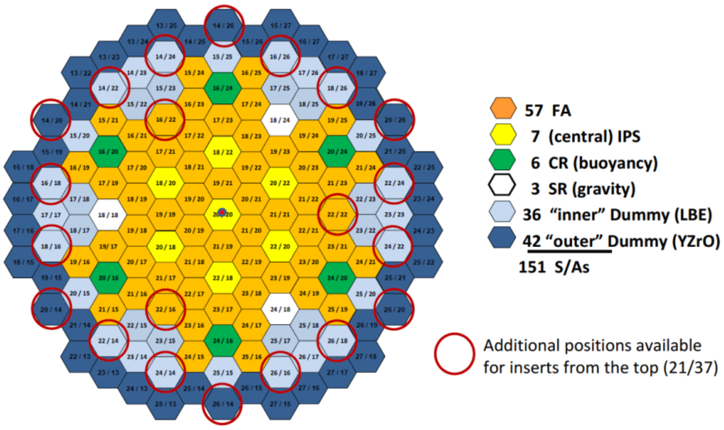


A. Reactor vessel
B. Reactor cover
C. Diaphragm
D. Primary heat exchanger
E. Primary pump
F. In-vessel fuel handling machine
G. Core
H. Above core structure
I. Core restraint system



In the present state of the design, the reactor core (Figure 4) consists of MOX fuel pins, typical for FRs. The central hexagonal position of the MYRRHA core houses a windowed beam tube-type spallation target. Thirty-seven positions can be occupied by in-pile sections (IPSs), or by the spallation target (the central one of the core in sub-critical configuration), or by control and shutdown rods (in the core critical configuration). This gives large flexibility in the choice of a more suitable position (neutron flux) for each experiment.

Figure 4: Section of the MYRRHA core



In sub-critical mode, the spallation target assembly, located in the central position of the core, brings the proton beam via the beam tube into the central core region. The assembly evacuates the spallation heat deposit, guarantees the barrier between the LBE and the reactor hall, and assures optimal conditions for the spallation reaction. The assembly is conceived as an IPS and is easily removable or replaceable.

Differently from the critical layout, in ADS mode the six control rods (buoyancy-driven in LBE) and the three scram rods (gravity-driven in LBE) will be replaced by absorbing devices to be adopted only during refuelling. Thanks to the (aimed and reached) flexibility, such absorbing devices will be implemented by adopting the control rods, but they will be controlled manually only by the operator.

A detailed description of the MYRRHA facility is given in a companion paper of this conference [11].

Updated planning for MYRRHA

The duration of the preparation phase of the MYRRHA project has been updated with about 2-year extension with respect to previous publications. This preliminary extension has been caused by several factors:

- The choice of the FEED contractor has been made in conformity with a European open call for tenders that is very time-demanding.
- The licensing scheme of the project has been, subdivided into two phases: a pre-licensing phase that will last at least 4 years followed by a licensing phase to come later.
- The research activities, which run in parallel to the design, have been deeply evaluated and their planning has been adapted and this induces also some delays.

The project will be undergoing a full evaluation at the end of 2014 with the Belgian government financing authorities to assess the next stages of the project.

Conclusion

The strategy of the European Commission for preparing the implementation of P&T as a high-level waste management approach complementing geological disposal is reaching an interesting stage of pilot-scale demonstration. The first building block, advanced reprocessing of spent fuel at ATALANTE in France, is progressing and delivering very promising results. The second building block has made a major step compared to few years ago thanks to the Institute for Transuranium Elements (ITU) of the Joint Research Centre (JRC) of the European Commission in Karlsruhe, Germany, which is upgrading the MALAB (Minor Actinides LAB) capabilities up to 250 kg (Pu+MA) transuranic materials. The third building block of dedicated burners is addressed through two projects in development in Europe: the ASTRID SFR prototype in France and the MYRRHA ADS project in Belgium, which is discussed in this paper. The fourth block presently not heavily addressed in Europe; this is a mandatory step in the future for all programmes of advanced reprocessing such as pyro-reprocessing.

MYRRHA is foreseen to be operated in both sub-critical and critical modes. In sub-critical mode, it will demonstrate the ADS technology and the efficient transmutation of MAs in sub-critical mode. As a fast spectrum irradiation facility, it will address fuel research for innovative reactor systems, material research for Gen IV systems and for fusion reactors, radioisotope production for medical and industrial applications such as Si-doping.

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