FROM MYRRHA TO XT-ADS: THE DESIGN EVOLUTION OF AN EXPERIMENTAL ADS SYSTEM

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The EUROTRANS project is an integrated project in the 6th European Framework Program in the context of Partitioning and Transmutation. It 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. This project, started in April 2005, is scheduled for 48 months.

*Since 1998, SCK•CEN has been designing a multipurpose ADS for R&D applications – MYRRHA. In its 2005 version, MYRRHA consists of a proton accelerator delivering a 350 MeV*5 mA beam to a windowless liquid Pb-Bi spallation target that in turn couples to a Pb-Bi cooled, sub-critical fast core of 50 MW thermal power.*

The EUROTRANS partners have accepted the SCK•CEN offer to use MYRRHA as a starting basis for the XT-ADS design. Instead of starting from a blank page, this allowed optimizing an existing design towards the XT-ADS needs within the limits of safety requirements. Many options have been revisited in 2005 – 2006 and the framework is now set up.

In this paper we present the general configuration of the XT-ADS core and primary system, with a particular focus on the evolution from MYRRHA and the rationale behind.

I. INTRODUCTION

SCK•CEN in partnership with Ion Beam Applications s.a. (IBA) and many European research laboratories, is since 1998 designing a multipurpose ADS for R&D applications – MYRRHA[1,2]. In parallel, SCK•CEN is conducting an associated R&D support program addressing the key issues of the design options and the associated heavy liquid metal technology chosen in the project. MYRRHA aims to serve as a basis for the European experimental ADS providing protons and neutrons for various R&D applications. It consists in its "2005" design version[3] of a high power proton accelerator of 350 MeV*5 mA proton beam bombarding a liquid Pb-Bi spallation target that in turn couples to a 50 MW thermal power, Pb-Bi cooled, sub-critical fast core.

Along the above design features, in a first stage, the MYRRHA project was intended to fit into the European strategy towards an ADS Demo facility for nuclear waste transmutation as described in the PDS-XADS FP5 project[4] and EUROTRANS FP6 Project[5]. For a later stage, the MYRRHA/XT-ADS project is developed as a multipurpose irradiation facility for R&D applications based on ADS technology. As such, it should serve the following task catalogue:

- ADS concept demonstration
- Safety studies for ADS
- Minor Actinides transmutation studies
- Long Lived Fission Products transmutation studies
- Medical radioisotopes production
- Material research
- Fuel research

The present MYRRHA/XT-ADS design is driven by the flexibility and the versatility needed to serve the above applications. Some choices are also conditioned by the objective making it as demonstrative as possible, with the final goal to be able to assess the feasibility of an industrial ADS prototype. The design team has favored as much as possible mature or less demanding technologies in terms of R&D. Nevertheless, not all the components are existing. Therefore, a thorough R&D support program for the innovative components or technologies has been started since 1997 and has been updated on a regular basis.

II. THE MYRRHA 2005 DESIGN FILE

The MYRRHA project[3] is based on the coupling of a proton accelerator with a liquid Pb-Bi windowless spallation target, surrounded by a Pb-Bi cooled sub-critical neutron multiplying medium in a pool type configuration with a standing vessel (see Figure 1). The spallation target circuit is fully immersed in the reactor pool and interlinked with the core but its liquid metal content is separated from the core coolant. This is a consequence of the windowless design presently favored, which allows to use "low" energy protons on a very compact target at high beam power density (~150 µA/cm²). In this way, one can reach high flux levels in the core with still a reasonably low total thermal power.

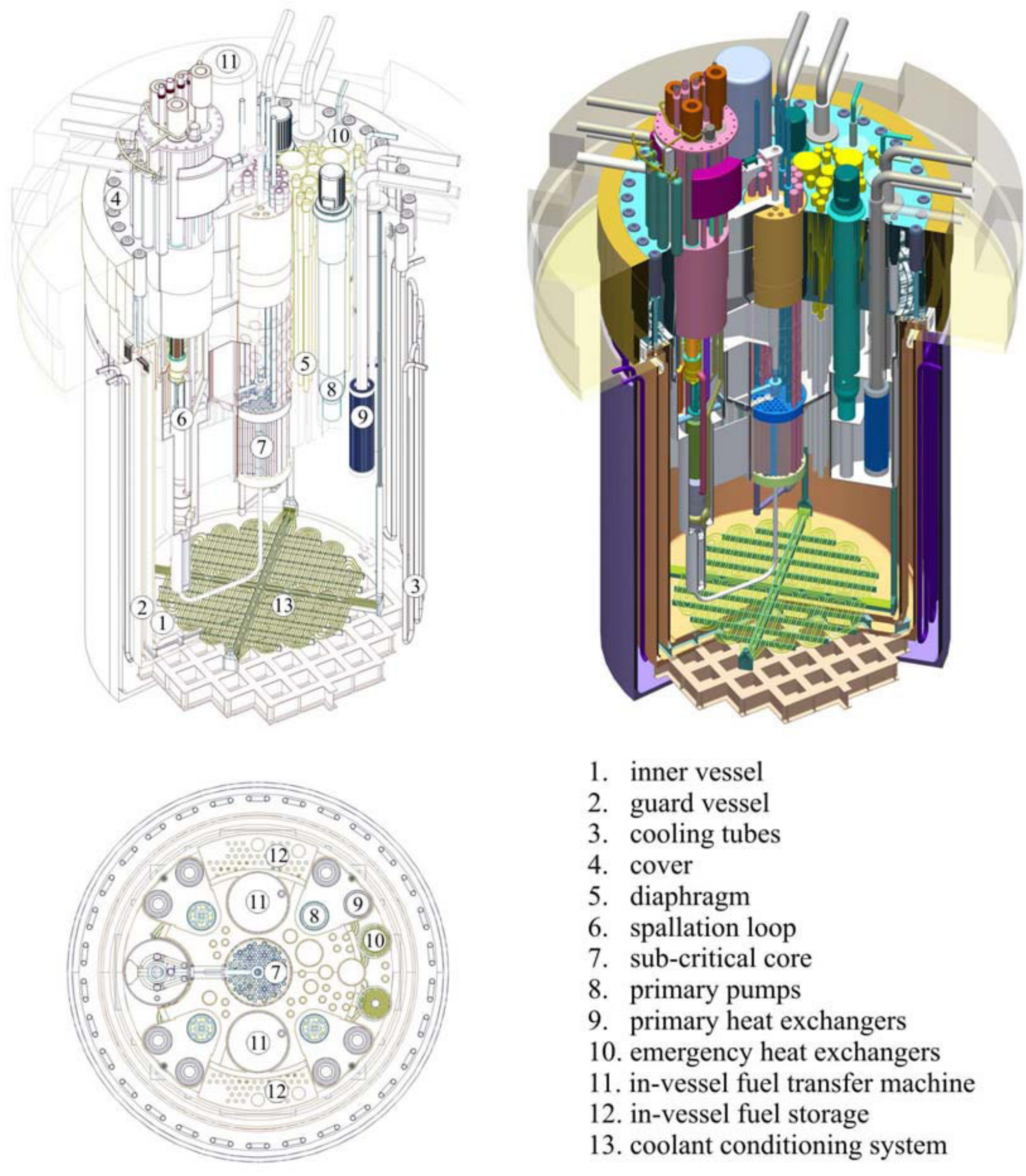

Figure 1: MYRRHA 3-D Vertical View

The core pool contains a fast-spectrum sub-critical core cooled with Pb-Bi eutectic (LBE) and several in-pile sections housing thermal spectrum regions located in the fast core. This core is fuelled with typical MOX fast reactor fuel pins with total Pu-contents of 30% and 20% with an active length of 600 mm. The pins are arranged in hexagonal assemblies of ~85.5 mm flat-to-flat (including the fuel assembly canister thickness of ~2 mm). The three central hexagons are left free for housing the spallation target module.

The core structure is mounted on a central support column coming from the lid and being stabilized by a conical diaphragm, the separating septum between the cold and hot LBE coolant, which is fixed ultimately to the rim of the double-wall vessel. Since access from the top is very restricted and components introduced into the pool will be buoyant due to the high density of the LBE, the loading and unloading of fuel assemblies is foreseen to be carried out by force feed-back controlled robots in remote handling from underneath.

The pool contains also the liquid metal primary pumps (PP), the heat exchangers (HX) using pressurized water or boiling water as secondary fluid[6]. The four PP and eight HX of the facility are able to extract up to 80 MW of thermal power. These components are arranged in four groups each one consisting of two HX and one PP located in a casing. There are also two fuel handling robots based on the well known rotating plug technology of fast reactors located within the vessel.

The spallation circuit connects directly to the beam line and ultimately to the accelerator vacuum. It contains a mechanical impeller pump and a liquid metal/liquid metal heat exchanger using the primary reactor coolant (of the cold plenum) as the secondary fluid. For regulation of the position of the free surface on which the proton beam impinges (whereby this defines the vacuum boundary of the spallation target), it comprises an auxiliary magneto-hydro dynamic pump. Further on, it contains services for the establishment of proper vacuum and an O_2 concentration control system that maintains corrosion limiting conditions.

The device shown in Figure 1 with the double-wall pool containment vessel (inner diameter of 4.4 m and height close to 7 m), is surrounded by biological shield to limit the activation of the surrounding soil as the MYRRHA sub-critical reactor is installed in an underground pit. This shield is closed above the vessel lid by forming an α-compatible hot cell and handling area for all services to the machine. The reactor hall is considered to be operating with an inert atmosphere in order to limit lead oxide formation when opening the reactor lid or extracting any device out of the reactor vessel.

III. FROM MYRRHA TO XT-ADS

Already in the beginning of the EUROTRANS project, SCK•CEN offered to use the MYRRHA 2005 design file as a starting basis for the XT-ADS design[7]. This allowed optimizing an existing design towards the needs of XT-ADS and within the limits of the safety requirements instead of starting from a blank page. MYRRHA and XT-ADS differ however on several topics that are listed below for each field of the design and are detailed for the core design and for the general configuration of the primary system.

The reference accelerator for XT-ADS has a 600 MeV beam while it was limited to 350 MeV for MYRRHA, the latter value being however kept as backup option. The core inlet and outlet temperature have been significantly increased and reach now 300°C (inlet) and 400°C (outlet). On the other hand the fuel power density has been limited to 700 W/cm³, while it reached 1000 W/cm³ for MYRRHA. The thermal power of the installation should range between 50 and 70 MW_{th}.

As in MYRRHA, the XT-ADS is designed to use MOX as fuel material[8]. Both designs start with a 30wt% of plutonium MOX. While MYRRHA was designed using a *reactor grade* plutonium vector, for XT-ADS we opted for a plutonium vector coming from the *reprocessing* of PWR fuel (initial enrichment of 4.5% in ^{235}U, burn-up of 45 GWd/t, cooling period of fifteen years).

The pin itself (Figure 2) consists of a fuel pellet column of 60 cm with on both ends a neutron reflector to increase the neutron economy, a fission gas plenum and a closing cap.

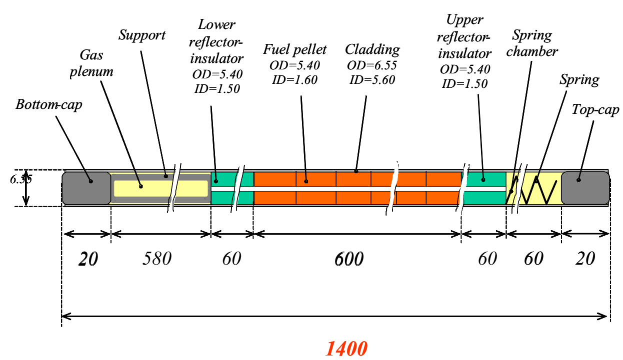

Figure 2: XT-ADS fuel pin

The fuel pellets are of the hollow type (diameter = 1.6 mm). This reduces the centerline temperature and hence gives larger margins to fuel melting limits. The fuel assembly contains 90 of these fuel pins in a hexagonal lattice together with one "instrumentation pin" in the centre of the assembly.

Another major difference with the MYRRHA design is the larger fuel pin pitch. This increase was needed to reduce the pressure drop over the core. It was very clear from the beginning that the T91 cladding material would be the weakest link and hence defining the operational limits of the XT-ADS core. The present design is the result of several iterations between neutronic and thermo-hydraulic calculations. The most important feedback parameters were the pressure drop over the core and the needed coolant speed to keep the inlet and outlet temperatures fixed to the ones fixed in the characteristics (300°C – 400°C). Mechanical calculations showed that a wall thickness of 2 mm was sufficient for the wrapper. The clearance between the assemblies was fixed to 3 mm, which is the double of that of MYRRHA. The final result (Figure 3) is an assembly total width (flat-to-flat) of 93.2 mm and an assembly pitch (center-to-center) of 96.2 mm.

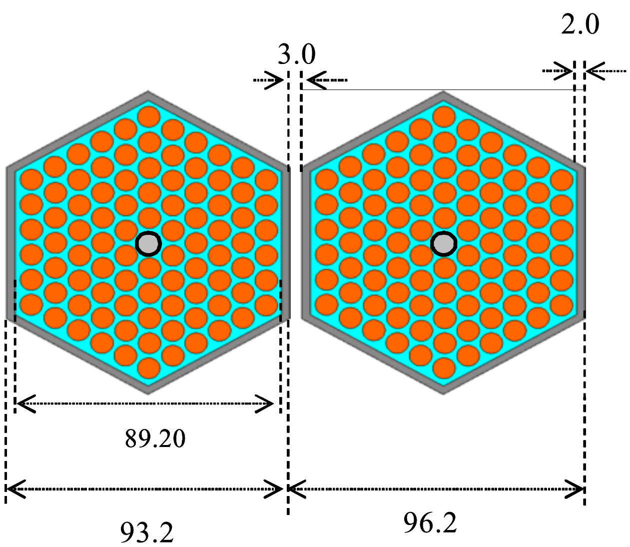

Figure 3: XT-ADS fuel assembly

As a result of both the degrading of the MOX fuel and the enlargement of the fuel assemblies and assembly pitch (the fuel density has been reduced significantly) the k_{eff} of the core dropped. Three options were open to get back to the reference value of k_{eff} = 0.95: either increase the active length, or use more fuel assemblies, or allow for a higher Pu ratio (more than 30wt %). After several discussions with the partners of the project, it was decided to go for the third option. With a 31.5wt percentage, we reach indeed k_{eff}=0.953.

The core layout (Figure 4) was fixed to 72 fuel assemblies (in the center of the figure) encircling a "gap" of three emptied positions to allow for the placement of the spallation target module. The design group decided also to fix the proton beam current of the 600 MeV beam in order to have a fuel power density of 700W/cm^3. This results in a beam current of 2.33 mA, a core power of about 57 MW_{th} and a fast peak flux $\Phi_{>0.75MeV}$ of 0.72 10^{15} n/(cm².s).

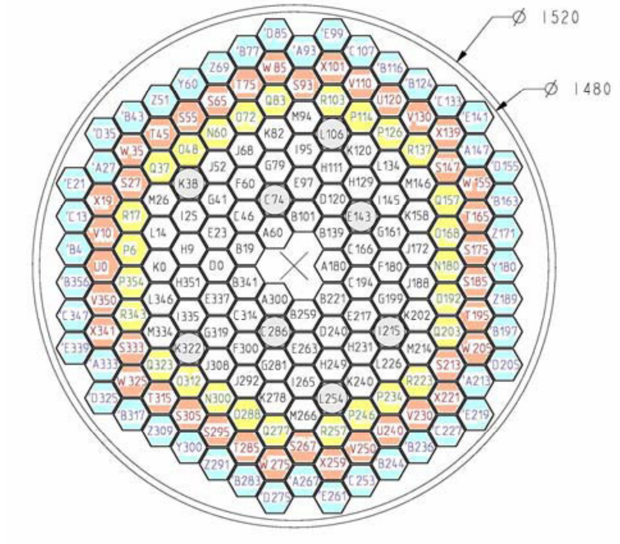

Figure 4: XT-ADS core

The design of the XT-ADS spallation target[9] also started from the MYRRHA design and the modifications described above. If some topics should in principle facilitate the design (using larger fuel assemblies implies more room for the target, lower energy deposited by the 600 MeV proton beam), such a design requires quite a lot of R&D effort already on-going.

IV. THE PRIMARY SYSTEM EVOLUTION

For the vessel configuration including the primary system, we also started from the MYRRHA design and include some enhancements suggested by the partners.

A large part of the work has been devoted to investigate the possibility of fuel handling from the top. Although fuel loading from the bottom, like in the MYRRHA design, is far from the classical options in reactor technology, fuel loading from beneath the core was still preferred.

The main advantage of such solution is a minimized interference with the experimental rigs (in-pile sections) that are (un)loaded from the top and must be kept in position during fuel loading operations. Interference with the spallation loop, with the instrumentation above the core and with the beam line tube is also minimized. The classical option of fuel handling from the top would therefore penalize the plant availability. A final advantage of the loading by the bottom is the possibility to avoid a fuel assembly locking system for buoyancy reasons.

Seismic events were considered in the fuel assembly as well as in the vessel design; there is no need to install seismic dumpers since the very smooth seismic activity at the Mol site.

The present XT-ADS design, currently under study within EUROTRANS, is illustrated by Figure 5 – cross section – & Figure 6 – vertical section – and differs quite a lot from the MYRRHA design presented in Figure 1:

1. Core
2. Heat exchangers (2 x 2)
3. Pumps (2 x 1)
4. Spallation loop
5. Fuel manipulators (2 units)
6. Vessel

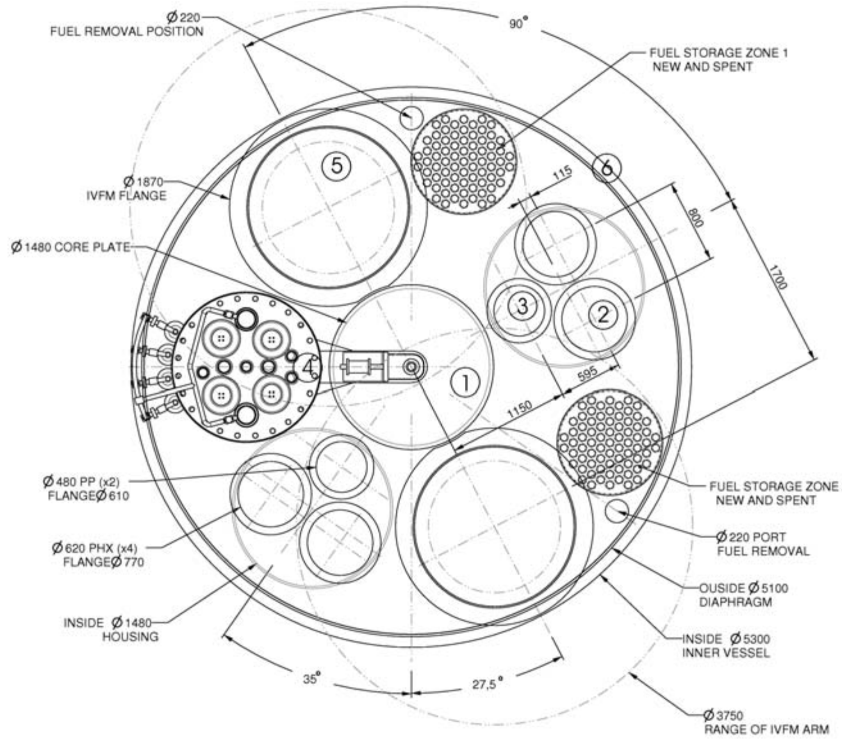

Figure 5: XT-ADS cross section in the vessel

- the reactor and safety vessels have now an elliptical bottom and are hanging (while MYRRHA was standing); a special shape has been adopted for reducing the thermal loads on the vessel support;
- the shape of the diaphragm has been changed from conical to cylindrical to minimize the core bypass flow-rate, to reduce the mechanical loads and to improve its constructability; the number of the penetrations in the diaphragm has also been reduced for the same reasons;
- the number of primary components was kept as low as possible to reduce the plant cost and maintenance without jeopardizing safety functions and availability; a comparison exercise was performed and the final chosen configuration contains two groups (MYRRHA had four groups) of each one primary pump and two boiling water heat exchangers;
- the primary system has been designed to evacuate a total of 70 MW_{th} (this value takes into account not only the core, but also the spallation target, the decay heat from the fuel storage and other minor heat sources) by two independent secondary loops using water that boils in the primary heat exchangers and condensing the produced steam in the air coolers cooled by forced air;
- the elevation of the HX with regard to the core has been increased to improve natural circulation capabilities;

- the secondary system is designed as a safety grade system and is able to evacuate the decay heat also in emergency conditions in natural circulation with 200% of redundancy.
- "reactor vault cooling system" has been adopted as ultimate decay heat removal in case of loss of heat sink.

1. Core
2. Heat exchangers (2 x 2)
3. Pumps (2 x 1)
4. Spallation loop
5. Vessels
6. LBE hot level
7. LBE cold level

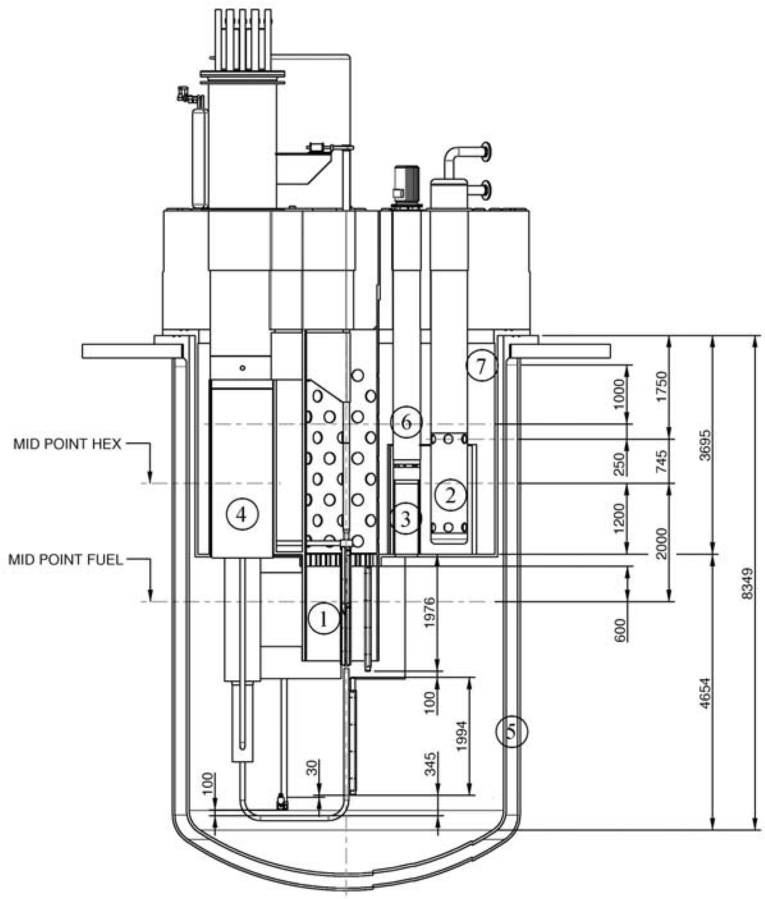

Figure 6: XT-ADS vertical section through the vessel

V. THE PERSPECTIVES FOR IMPLEMENTATION

The EUROTRANS FP6 project will end in March 2009. The conceptual design of the machine and of its different components will be then available. Informal discussions with the Belgian safety authorities concerning the MYRRHA/XT-ADS project already exist today. We foresee also to submit at the end of 2008 a Preliminary Decommissioning Plan to the waste management authorities. We foresee then for the period 2009 – 2013 to work in parallel on:

- the detailed engineering design, including three years (2009 – 2011) of technical work, followed by two years (2012 – 2013) for the drafting of the technical specifications of the different procurement packages, the publication of the call for tenders, the comparison of the technical and financial proposals from the contractors and finally the awarding of the manufacturing contracts;
- the development and testing of several innovative components (for the accelerator and for the reactor);
- licensing and authorizing activities will be entering a formal frame, namely the redaction of

a Preliminary Safety Assessment Report and of an Environment Impact Assessment during the year 2009. Those reports together with the results of the decommissioning evaluation will be submitted begin 2010 to the safety authorities for an iterative evaluation process, the objective being to obtain the authorization of construction at the end of 2013.

A three-year period (2014 – 2016) will be then devoted to the construction of those components and to the civil engineering works on the Mol site. Assembling together the different components is planned for 2017. The years 2018 – 2019 would be devoted to the commissioning at progressive levels of power. And finally MYRRHA/XT-ADS would be fully operational in 2020.

VI. CONCLUSIONS

In this paper we have presented shortly an ambitious project for Belgium and Europe resulting from an in depth work conducted at SCK•CEN for about a decade, starting from an internal project with bilateral collaborations, going through its integration in a large multi-disciplinary European programme (EUROTRANS) and where real perspectives for construction exists in a nearby future. SCK•CEN wants to share today at largest the enthusiasm and the confidence that are driving this project.

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