# A European Advanced Technology Programme for ADS Accelerator Development

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# A EUROPEAN ADVANCED TECHNOLOGY PROGRAMME FOR ADS ACCELERATOR DEVELOPMENT*

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*Abstract*

Consecutive to the work of the European Technical Working Group on ADS, the Preliminary Design Study of an Experimental ADS was launched in 2001 as a 5th Framework Program EC project. A special working package was dedicated to the accelerator design, and in particular taking into account that the issue of "beam trips" could be a potential "show-stopper" for ADS technology in general. A reference solution, based on a linear superconducting accelerator with its associated doubly achromatic beam line has been worked out up to some detail. For very high reliability, the proposed design is intrinsically fault tolerant, relying especially on highly modular "de-rated" components associated to a fast digital feedback system. A programme for the remaining R&D, focused on experimental reliability demonstration of prototypical components, has been elaborated. This R&D will be performed in the 6th Framework Program EC project EUROTRANS, which presently is just starting.

## INTRODUCTION

For dedicated transmutation systems, a sub-critical system using externally provided additional neutrons is very attractive: it allows maximum transmutation rate while operating in a safe manner. An ADS (Accelerator Driven System), coupling a proton accelerator, a spallation target and a sub-critical core, could be used as such a reactor. Consecutive to the initial work of the Technical Working Group on ADS technology [1], the project PDS-XADS, Preliminary Design Study of an eXperimental ADS, was funded by the European Commission in 2002 [2], and studied 3 versions of an XADS: both a molten-metal (eutectic Pb-Bi) and a gas cooled ADS of 100 $MW_{th}$ class, and a smaller-scale (≈ 50 $MW_{th}$) system based on the MYRRHA project of SCK Mol (Belgium) [3]. The PDS-XADS contract ended in October 2004. Below we first give a short summary of the main results as far as the accelerator is concerned, and then present the required R&D, part of the FP6 project EUROTRANS that started in April 2005. An overview of the related SCRF work done at IPN Orsay is also given.

## THE XADS REFERENCE ACCELERATOR

The XADS accelerator belongs to the category of "HPPA" (high-power proton accelerators), which are presently very actively studied (or even under construction) for a rather broad use in fundamental or applied science. Compared to other HPPA, many specifications of the XADS driver are similar: 600 MeV final energy (350 MeV for the smaller-scale ADS), 6 mA CW beam, 2% beam power stability, 10 % beam size stability on target, etc. [4]. But it is to be noted that the reliability requirement, i.e. the number of unwanted "beam-trips", is rather specific to ADS. This reliability requirement is essentially related to the number of allowable beam trips, because, frequently repeated, they can significantly damage the reactor structures, the target or the fuel, and also decrease the plant availability. Therefore, beam trips in excess of 1 second duration should not occur more frequently than 5 per year. The studies had to integrate this stringent requirement from the very beginning, since this issue could be a potential "show-stopper" for ADS technology in general.

The chosen strategy to implement reliability relies on over-design, redundancy and fault-tolerance [5]. This approach requires a highly modular system where the individual components are operated substantially below their performance limit ("de-rating" principle): in contrast to a cyclotron, a superconducting linac, with its many repetitive accelerating sections grouped in "cryomodules", conceptually meets this reliability strategy.

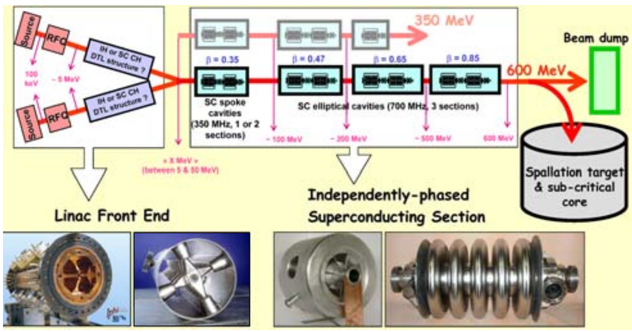


Figure 1: The XADS reference accelerator.

The proposed reference design for the XADS accelerator, optimized for reliability, is shown in Figure 1 [6]. For the injector, an ECR source with a normal conducting RFQ is used, followed by warm IH-DTL or/and superconducting CH-DTL structures up to a transition energy still to be optimized around 20 MeV. Then a fully modular superconducting linac accelerates the beam up to the final energy.

Below the transition energy, fault-tolerance is guaranteed by means of a "hot stand-by" spare injector, making use of the redundancy principle. Above this energy, spoke and, from 100 MeV on, elliptical cavities are used. This superconducting section, that uses highly over-designed and independently-powered accelerating components, is intrinsically "fault-tolerant": beam dynamic calculations showed that an individual cavity failure should be handled "on-line" at all stages without

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loss of the beam by using the local compensation method [7], which principle is illustrated in Figure 2.

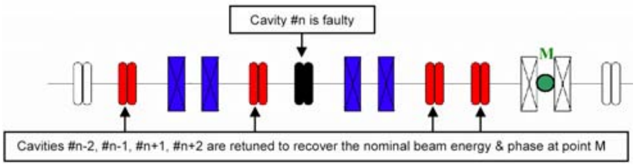


Figure 2: The "local compensation" method.

## EUROTRANS: THE R&D PROGRAMME

The broad field of applications covered by HPPA accelerators is at the origin of a remarkable R&D effort presently underway world-wide. The study, design and testing of the main components of these new generation linear accelerators have contributed to a good synergy by developing complementary activities between many laboratories. The XADS accelerator can profit from this general background and even built on it quite directly. However, a dedicated R&D programme is needed for the requirement of an extremely low number of beam trips. In this spirit, such a programme has been recently launched, focused on reliability and fault tolerance design. It is included in the 4 year 6$^{th}$ FP project EUROTRANS, that started in April 2005. The five main tasks of this programme are discussed below.

### *Evaluation of the injector reliability*

Concerning the injector section, a thorough campaign to test the reliability of every component of the injector, operated over a long period of time (e.g. a continuous run of many weeks), will be performed "full-scale" with IPHI. Presently under construction in France [8], IPHI, consisting of an already operational ECR source and a 6 m long RFQ, will deliver, in 2006, its 3 MeV high intensity beams (10 - 100 mA). The experimental results are expected before mid 2008.

### *R&D for the intermediate energy section*

Some basic R&D is required for the subsequent sections, up to 100 MeV, in order to assess a solution simultaneously reliable and economical. While SC components should in principle be deployed from the lowest possible energies on, room-temperature structures have nevertheless to be studied and prototyped: the transition energy to the superconducting structures might be higher than the RFQ output and, while room-temperature structures have large RF losses, their development risk is low (well established technology). The superconducting resonators considered here are CH structures before the transition energy, because of their very promising efficiency, and spoke cavities after, because they are short and modular in view of the fault-tolerance strategy. First SC cavity prototypes are presently successfully tested, showing performance exceeding the specifications for the XADS by a very comfortable over-design safety margin [9,10]. It is therefore important to push these developments by adding helium tanks and power couplers. The final aim of all these developments is to assess the best technical option for the intermediate section of the XADS accelerator based on established demonstrated performance. It might well be a combination of several technologies.

### *High-energy section cryomodule*

While the R&D on 704 MHz superconducting elliptical cavities is well advanced in Europe, the demonstration of the full technology is not yet accomplished. Besides the development of the bare superconducting cavity, it is important to prototype each auxiliary system needed for the cavity operation in a real environment (power coupler, RF source, power supply, RF control system, cryogenic system, cryostat…). The construction of a full-scale module with a given beta value ($\beta = 0.5$) can be considered as a rather general proof-of-principle of the technology, since the higher beta modules are very similar. The construction and test with RF at nominal power (although without beam) of such a module should be done before end 2008.

### *Digital LLRF control system*

The performance of the RF control system procedures in case of a cavity failure is a major key to reach the reliability requirement. Indeed, the reaction speed for retuning the whole accelerator to nominal beam conditions must be less than 1 second for fault-tolerance. Digital techniques are necessary to meet the speed and software configuration requirements. It is planned in this task to perform a full conceptual design of such a specific low-level RF system for the 704 MHz elliptical section.

### *Accelerator design*

This last task will ensure the overall coherence of the accelerator design. Beam dynamics simulations will be performed, in close collaboration with the LLRF task, to assess the adequate transient procedure while dealing with a cavity failure. An integrated reliability analysis of the whole linac will also be made, the final goal being to obtain in 2009 a frozen detailed design of a XADS linac, with assessed reliability and costing.

## RELATED SCRF ACTIVITIES AT IPNO

All these tasks will be performed within the Work Package WP 1.3 of the EUROTRANS project. IPN Orsay, which is coordinating this WP, is contributing in each of this task, with a special involvement in the following SCRF activities.

### *352 MHz spoke cavities*

Several successful tests on spoke 2-gap cavities have been reached since 2002 at Orsay on beta 0.35 and beta 0.15 prototypes. This active R&D is going on [11], both in the EUROTRANS and the EURISOL context. The following steps consist now in developing a cold tuning system and a 10 kW CW power coupler, with the perspective to perform in 2008 a test at nominal power in the horizontal cryostat CM0, shown in Figure 3.

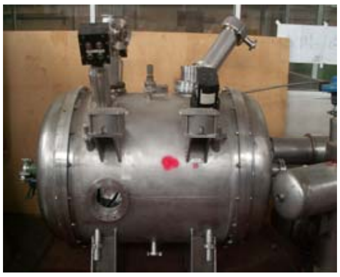

Figure 3: The CM0 module for spoke cavities.

### *704 MHz elliptical cavities*

A R&D activity on 704 MHz cavities is going on at IPN Orsay since 1998, in collaboration with CEA Saclay and INFN Milano, with several successful tests of single-cell and multi-cell cavities. IPN is presently involved in the development of a cold tuning system [12], and of a 150 kW CW power coupler for these cavities [13], as shown in Figure 4. The EUROTRANS $\beta = 0.5$ cryomodule will be designed together with INFN Milano, and assembled and tested at Orsay in 2008.

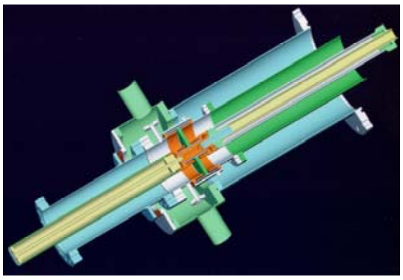

Figure 4: Sketch of the 704 MHz high power coupler.

### *LLRF & beam dynamics developments*

The analysis of the SC linac fault-tolerance capability is one of the major task of EUROTRANS. In this view, specific beam dynamics tools are developed in collaboration with CEA Saclay to look at the transients induced by the "local compensation method", and to assess realistic fault recovery scenarios. In parallel, a R&D programme has started in 2004 at Orsay to build a prototypical digital LLRF system for 352 MHz spoke cavities, in collaboration with CNRS/IN2P3/LPNHE, and in close link with the EUROTRANS LLRF work made at CEA Saclay at 704 MHz. The first prototype, which is under fabrication, will be tested in 2006.

## CONCLUSION

Within the 3 year contract PDS-XADS, a generic and robust technical solution for the XADS accelerator has been developed. A superconducting linac has been found to constitute an optimal technical solution through the rigorous implementation of a highly modular system with "de-rated" components operated in a fault-tolerant way. A validation R&D programme, focused on reliability and coordinated by IPN Orsay, will be performed within the FP6 project EUROTRANS so as to obtain in 2009 a frozen detailed design of a XADS linac, with assessed reliability and costing.

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