Nuclear Development

Accelerator-driven Systems (ADS) and Fast Reactors (FR) in Advanced Nuclear Fuel Cycles

A Comparative Study

NUCLEAR ENERGY AGENCY
ORGANISATION FOR ECONOMIC CO-OPERATION AND DEVELOPMENT

Annex F

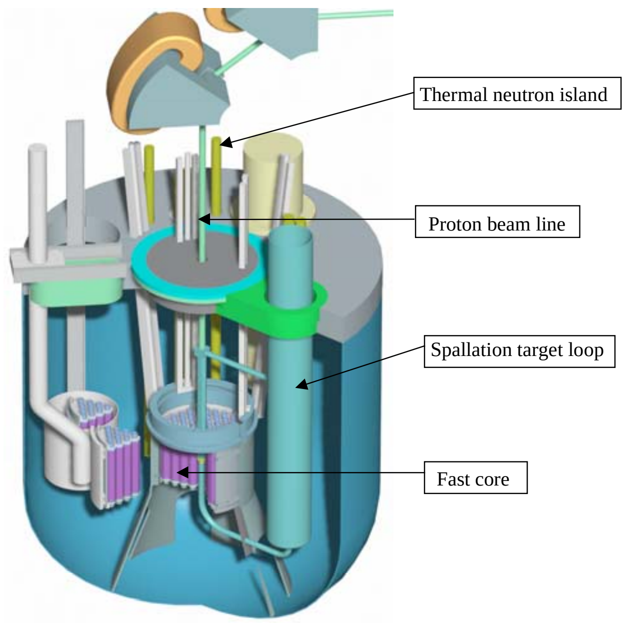
OVERVIEW OF NATIONAL AND INTERNATIONAL ADS PROGRAMMES

Belgium

SCK•CEN is at the present time finalising the pre-design of an ADS prototype called MYRRHA (see Figure F.1). MYRRHA is intended to be a multipurpose R&D irradiation facility. One of its main purposes is investigating the feasibility of actinide transmutation. Other ADS-related research topics concern materials and fuel behaviour, the utilisation of liquid metals and the associated issues, the reactor physics and safety of sub-critical systems, and the production of radioisotopes. The planned design period till 2003 will continue at the initial pace of the previous years. Construction of the Myrrha pre-prototype depends on a specific authorisation by the government.

The accelerator part of the device, presently designed by IBA, is to deliver a 350 MeV, 5 mA proton current. A neutron yield slightly higher than 3 per proton is expected at this energy. The spallation source would be Pb-Bi, windowless design, with an outer diameter of about 72 mm. The sub-critical core (k_{eff} 0.95) consists of an annulus, around the spallation source, of Pb-Bi cooled FR-type MOX assemblies (active length: 50 cm) with high Pu content (up to 30% in some zones). The fast zone is to be further surrounded by thermal "islands" in separate in-pile sections, with low neutron flux coupling to the fast core. The total power of MYRRHA should not exceed 30 MWth. Fast fluxes (E>0.75 MeV) up to 1 015 n/cm^2·s are to be attained in irradiation positions near the spallation source intended for minor actinide transmutation.

Figure F.1 **Conceptual view of MYRRHA**



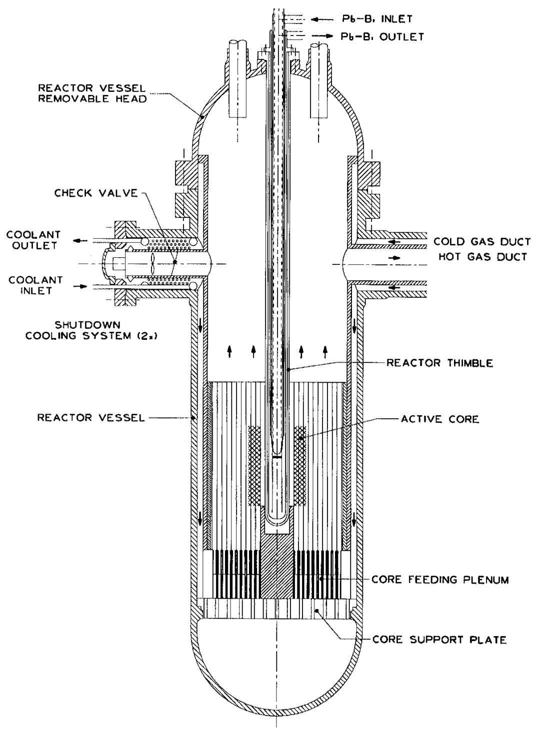
France

A research group (GEDEON) made up of CNRS, CEA, EdF and Framatome was launched in 1996 to co-ordinate the activities within France related to P&T. This co-operation was a means to intensify and co-ordinate the research requested by the 1991 law. The main options for the XADS have been defined in 1998 by a French working group leaded by the Ministry of Research and grouping CEA, CNRS, EDF and Framatome. The main technical options are as follows:

- A proton beam with energy between 400 MeV and 1 GeV, impacting on a heavy metal spallation target.
- A sub-critical core in a fast neutron spectrum.
- A solid fuel for the transmutation of the radioactive wastes.
- A maximal power for the sub-critical core lower than 200 MW thermal.
- A physical separation ("window") between the accelerator and the spallation target.
- A physical separation between the spallation target and the reactor housing the sub-critical core.

Based on these main options, a XADS concept has been proposed by France at the European TWG. The concept is still preliminary and studies should be performed in the frame of the Fifth European Framework Programme to consolidate the proposed design. Gas has been chosen as cooling medium of the sub-critical core (See Figure F.2). It had been judged that this option should be investigated in order to propose an alternative to the liquid metal concepts using sodium, lead or lead-bismuth. Helium has been preferred owing to its thermal characteristics, and because the risk of chemical interactions, radiolysis and radioactive activation can be intrinsically excluded.

Figure F.2. **Gas-cooled XADS concept**



Activities have been performed in several areas including neutron cross section measurements, integral experiments at MASURCA, development of the IPHI accelerator and system studies. Today, a report to promote the development of a demonstration-ADS is being prepared.

A multi-purpose irradiation facility, called CONCERT (COmbined Neutron Centre for European Research and Technology), has been proposed by CNRS. This facility would use the secondary beams, produced by high energy protons in a spallation target, for research in muon science, nuclear/particle physics, neutron science, radioactive beams, materials research and also nuclear transmutation research. A five years feasibility and detailed engineering study is proposed while the total construction period for the installation and the experiments would take another 10 years.

Germany

At the Technical University Munich the design of a separated-orbit cyclotron, with super-conducting channel magnets and super-conducting RF cavities for a 1 GeV proton beam of up to 10 MW beam power, is under development (TRITON). The distinguishing feature of this type of cyclotron is the strong transverse and longitudinal focusing. Recently it was demonstrated that the principle works as anticipated with operation well above the design values.

In Germany, some small activities related to the application of ADSs for the back-end of the fuel cycle have been in progress for several years. The first main objective was to establish reliable calculation procedures in order to be able to compare ADS capabilities with those of critical reactors. Exploratory investigations have been performed for thermal systems with dispersed fuel in lead coolant at FZJ Julich and for Phénix-like fast systems at FZK Karlsruhe.

Italy

ENEA and INFN set up a basic R&D programme TRASCO aiming at the study of physics and technologies needed to design an ADS for nuclear waste transmutation. The programme consists of research sub-programmes on accelerator, neutronics, thermal-hydraulics analysis, beam window technology, and material technology and compatibility with Pb and Pb-Bi. An industrial programme was also set up to issue a reference configuration description of a low power ADS prototype.

ANSALDO has embarked, together with Framatome, on a design of a prototype gas-cooled or LBE-cooled ADS (XADS), which was proposed to the European Technical Working Group. Since early 1998, the Italian ENEA, INFN, CRS4 and Ansaldo have set up a team, led by Ansaldo, to design an 80 MWth XADS, a key-step towards assessing the feasibility and operability of an ADS prototype. The results obtained so far [1], though preliminary and not exhaustive, allow outlining a consistent XADS configuration (see Table F.1 and Figure F.3).

The concept is still preliminary and further studies will be performed in the frame of the Fifth European Framework Programme to consolidate the proposed design.

In support to the these ADS design activities, ENEA has decided to build CIRCE [2] – a Pool Test Facility based on LBE – which will allow to test the key operating principles of the LBE XADS. The basic configuration of CIRCE, including the first test section, has been completed and commissioned at the site of Brasimone (Italy) in 2001. The CIRCE facility will be shortly described in Chapter 7.

Table F.1. **XADS configuration**

Plant area	**Reference solution**
Plant power	80 MWth sub-critical system controlled by a 600 MeV, 6 mA proton beam
Target/Window	Two options: a) Proton window b) Windowless target
Core	0.97 (at beginning of cycle)<k_{eff} 0.94 (at end of cycle), at full power
Fuel	U and Pu MOX
Primary system	Pool configuration with four integrated IHXs
Primary coolant circulation	Circulation enhanced by gas injection in a natural-circulation reactor configuration
Secondary system	Two low vapour pressure organic diathermic fluid loops rejecting heat by means of air coolers
Thermal cycle	300^{o}C at core inlet, 400^{o}C at core outlet
Reactor roof	Metallic plate
Main vessel and safety vessel	Hung from a cold annular beam
Structural materials	Vessels and internals: 316L Target and fuel SA's: 9Cr 1Mo
In-vessel fuel handling	One rotating plug, one fixed arm, one rotor lifting machine
Secondary fuel handling	Flask, encapsulator, canister, lifting and translating equipment, water pool
Nuclear island	Common basement on anti-seismic support
Plant safety	Fully passive system

Japan

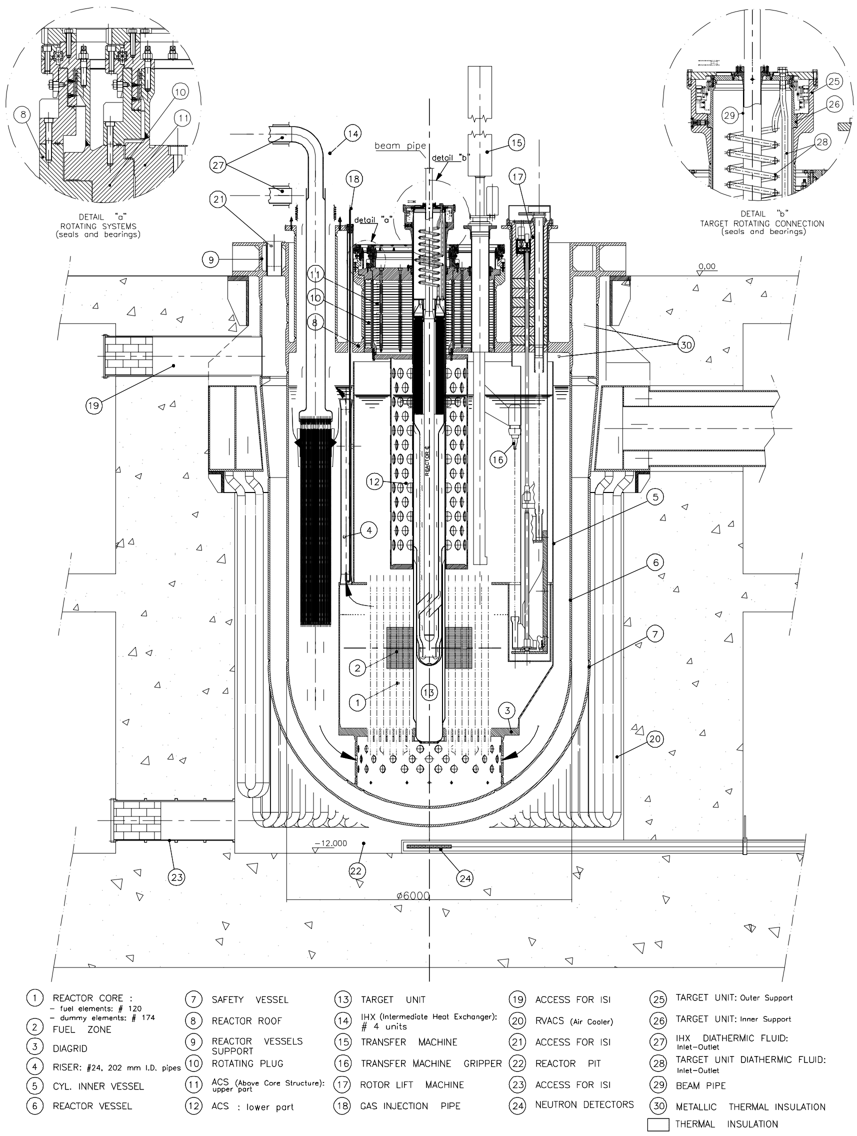
A preliminary design study of an 800 MWth lead-bismuth cooled accelerator-driven system (ADS) with nitride fuel has been directed towards a dedicated transmutation system to be deployed as the second stratum of a double-strata fuel cycle scheme. The plant has a pool-type configuration and a power conversion system operating on a saturated cycle (see Figure F.4).

An experimental program to develop and demonstrate accelerator-driven transmutation technology has been carried out under the project plan of the High Intensity Proton Accelerator and the OMEGA Program at JAERI. A pre-conceptual design study is being prepared for a transmutation experimental system. There are several technical challenges unique to the accelerator-driven transmutation system. The major areas of technology to be tested and demonstrated are sub-critical reactor physics, system operation and control, transmutation, thermal hydraulics, and material irradiation.

The typical sub-critical core configuration is based on that of the FCA (Fast Critical Assembly at JAERI) facility where various experiments can be conducted with changing core structure layout. The proton beam power will be 10 W with a proton energy of 600 MeV in pulses at a frequency of 25 Hz. The core thermal power is limited to 500 W, owing to the heat removal by forced air circulation.

Main integral measurements will be the reaction rate ratio and distribution, neutron spectrum, effects of high-energy neutrons, and sub-critical factor. System operation will be demonstrated and control experiments performed on beam trip effects, restarting operation and maintainability.

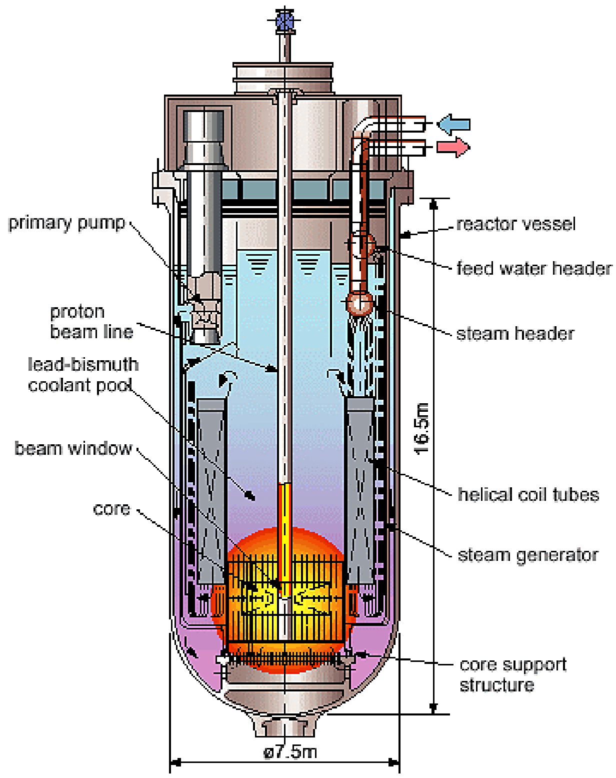
Figure F.3. **Scheme of a LBE-cooled XADS**



Furthermore, the engineering experiment facility is intended for research and development on beam window materials and thermal-hydraulic properties by using lead-bismuth target/loop equipment. As one of the most critical issues, corrosion/erosion in the lead-bismuth target/coolant system will be tested at operational temperature under proton and neutron irradiation. Material irradiation experiments will be performed with the proton beam power of 200 kW with 600 MeV and 25 Hz pulses in the first phase.

Most of the other important target and core technologies will be demonstrated through the experiments. In the planned scenario for developing the accelerator-driven transmutation system, the experimental program will proceed in a stepwise manner, according to the available power and the operating mode of the accelerator beam.

Figure F.4. **JAERI's design of a lead-bismuth cooled ADS with nitride fuel**



South Korea

A study on transmutation was initiated in 1992 at the Korea Atomic Energy Research Institute (KAERI). However, until 1995 the research was not very active. During this period, a sort of feasibility study was performed and some basic guidelines were set up to decide the research direction for transmutation. On the basis of these feasibility studies, an accelerator-driven sub-critical reactor was found to be the most promising candidate for incinerating nuclear waste from nuclear power plants. KAERI is setting up a long-term research programme called HYPER (HYbrid Power Extraction Reactor) and the schedule was drawn up in July 1997. The whole development schedule is subdivided into two phases. The basic key technologies are to be developed in Phase I (1997-2001) and a small bench scale test facility (~5 MWth) is to be designed and built in Phase II (2002-2006). Phase II will start only on condition that the Phase I research produces successful results. Therefore, a strict review will be performed within KAERI and the government just after Phase I. The expected major activities are: 1) developing a theoretical model to analyse coolant system behaviour, fuel system behaviour, and physics behaviour for the system design based on the experiments conducted in Phase I; 2) detailed design for the bench scale facility; 3) constructing a small scale facility; 4) doing performing a system safety analysis to obtain construction and operating permission from the regulatory body.

KAERI is also trying to launch a programme to develop a 1 GeV-20 mA multi-purpose linear proton accelerator called KOMAC. The design goal of the KOMAC is to generate protons of 1 GeV, 20 mA. It will be used for basic science research, radioisotope production, and transmutation technology development. The external review for the KOMAC system was done by international accelerator specialists in 1997. The user's program for the accelerator application was determined to be developed in parallel with the KOMAC program in that review workshop. The development schedule consists of two phases in combination with the HYPER program. The Injector, RFQ (3 MeV, 20 mA), DTL (20 MeV, 20 mA) and some low energy beam utilisation technology will be developed in Phase I (1997-2001) and the whole accelerator facility will be completed in Phase II (2002-2006).

Spain

CIEMAT launched in 1997 a P&T research program. The aim of the program is the study of ADS, with close attention paid to their applications in nuclear waste transmutation. The program has three main research lines. The first one is dedicated to the study of transmutation of long-lived radionuclides, including development of concepts, designs, operation models and computer simulation tools together with the participation in experiments on this field of research. The second line includes the partitioning of radionuclides, by hydrometallurgical and pyrometallurgical processes. The third line is dedicated to the study of materials that could be used in this type of systems, including in particular the use of Pb-Bi as coolant. Besides, several universities are participating in these projects. These research and development projects are supported by the Spanish Agency for Radioactive Waste Management (ENRESA).

Sweden

Research on P&T is mainly supported by the Swedish Nuclear Fuel and Waste Management Co. (SKB). The main activities occur at the Royal Institute of Technology in Stockholm, where physics, safety and other aspects of ADSs, are studied. The different research groups have strong international co-operative links and participate in projects supported by EU.

Switzerland

Nuclear energy research in Switzerland is concentrated at the Paul Scherrer Institute (PSI). Recent activities in the field of accelerator-driven systems and transmutation comprise investigations of the role and potential of accelerator-driven systems in advanced fuel cycles and possible benefits for the management of radioactive wastes, the validation of models in nucleon-meson transport codes by means of proton irradiation experiments, advanced fuel development, high-current cyclotron development, including conceptual design studies, and material technology development for liquid-metal spallation targets in the framework of the MEGAPIE initiative. Analytical studies in the reactor physics and safety area are planned.

The MEGAPIE experiment is currently set up at PSI as an international project with participation of CEA, FZK, CNRS, ENEA, SCK•CEN, JAERI, KAERI and US-DOE. The purpose of the experiment is to demonstrate the safe operation of a liquid metal target at a beam power in the region of 1 MW. The minimum design service life is one year (6 000 mAh). The target is scheduled for installation in the SINQ facility in 2004 or 2005. The major objectives of the MEGAPIE initiative are:

- Full feasibility demonstration of a spallation target system.
- Evaluation of radiation and damage effects of structures and beam window in a realistic spallation spectrum.
- Effectiveness of the window cooling under realistic conditions.

- Liquid-metal/metal interactions under radiation and stress.
- Post irradiation examinations.
- Demonstration of decommissioning.

A SINQ target irradiation experiment, in which miniature specimens of candidate structural and target materials are irradiated in special target rods, and the LISOR experiment, which allows liquid-metal/metal reactions under radiation and stress to be simulated in a liquid lead-bismuth loop set up at a 72 MeV proton accelerator, provide R&D back-up to the MEGAPIE experiment. Additional experimental R&D support to MEGAPIE is provided by the KALLA laboratory at FZK and by ENEA using the CIRCE loop at Brasimone.

The PSI activities in the field of accelerator-driven systems and transmutation are embedded in projects of the OECD/NEA and the fifth framework programme of the European Commission (EC). The respective EC projects are SPIRE, TECLA, HINDAS, CONFIRM, and PDS-XADS (for more information on these projects, see Chapter 7).

USA

In 1999 the US Congress directed the US-DOE to study the Accelerator Transmutation of Waste (ATW) project and to prepare a "roadmap" for developing this technology. In response to the congressional mandate, DOE developed, through the work of a steering committee and the national laboratories, an ATW roadmap that identified the technical issues to be resolved, proposed a schedule and programme, assessed the impact of ATW technology on the civilian spent fuel programme and estimated the costs of such a programme as well as identifying areas of development in other sectors and with other countries.

The roadmap exercise finally advised the US congress that an initial six-year programme of trade studies and science-based R&D on key technology issues, costing 281 million US$, would be prudent to increase the knowledge base to support future decisions.

Transmutation R&D in the US has been focused initially on accelerator-driven systems and has involved a series of trade-off studies. In all cases, it has been assumed that uranium remaining in civilian spent fuel elements would be recovered, probably by a modified Purex process called UREX. Initial studies of the UREX process have shown that the uranium product will meet US. Class C requirements and could be disposed of as low level waste or be stored for possible future use in a nuclear fuel cycle. The remaining process streams would be chemically separated into transmutation fuel material, long-lived fission product transmutation targets, and a waste stream that could be converted into durable waste forms capable of disposal in a high-level nuclear waste repository.

Various combinations of proton accelerator designs, spallation neutron sources, and transmutation target have been evaluated for technological readiness, and assumed irradiated targets have been studied for the effectiveness of chemical processing to recycle untransmuted long-lived isotopes. These evaluation have resulted in a base-line design which includes a linear proton accelerator (or Linac), a lead-bismuth spallation target, and sodium-cooled non-fertile elements of metallic or ceramic dispersion construction as transmutation targets or /blanket fuel. Other alternative designs have included cyclotrons as proton source, nitrides as transmutation targets, and tungsten spallation targets cooled by sodium, pressurised helium, or water.

Another interesting transmutation system design currently being evaluated consists of a "dual strata" approach which would involve a thermal critical reactor within which plutonium and minor actinides would fission, and ^{99}Tc and ^{129}I would be subjected to a thermal neutron flux. Technetium would probably be in metallic form and iodine as an iodide of sodium, silver or other stable cations. The thermal-spectrum reactor would be effective in burning plutonium-239 along with other actinides with high thermal fission cross-sections. Higher actinide isotopes would be produced by non-fissioning neutron capture, and after post-irradiation chemical processing, they would be the primary targets of an accelerator-driven transmutation system. Chemical processing of such targets after irradiation would result in actinide recycle to the ATW unit and recycle of ^{99}Tc and ^{129}I to the thermal reactor. High-level waste streams for repository disposal would be produced by the initial processing of civilian spent fuel, the recycle processing of spent fuel from the thermal reactor, and the ATW recycle process.

Since transmutation produces a net energy gain, it has been of interest to design systems capable of producing electric power to off-set transmutation expenses. One concern has been the current high "trip" rate of present generation accelerators, which may experience several unplanned cut-offs each day. Quite apart from safety considerations of thermal shock in the transmutation system, such interrupted power would have much lower value than conventional base-load systems. Early analysis indicates that more than ninety percent of the energy release in the "dual strata" would occur in the thermal reactor, so it may be possible to design the ATW system as a low-temperature actinide burner with much less stringent requirements for accelerator power and stability. Materials and corrosion problems in the ATW system would also be minimised. Studies of the concept are continuing.

Advanced Accelerator Applications (AAA)

The ATW program during the fiscal year 2001 involves approximately a doubling of the Fiscal Year-2000 funding. This will allow an expansion of experimental programs, and DOE's Office of Nuclear Energy, Science and Technology (NE) is actively seeking opportunities for collaborative research with foreign ADS programs. Meanwhile, the program is being reorganised to combine the objectives of the DOE Defence Programme's Accelerator Production of Tritium program with those of NE's ATW efforts. The combined programme is known as Advanced Accelerator Application, and it will be administered by NE. Congress has requested a report by March 1, 2001 on how the new activity will be carried out. It will be a public document, available on the World Wide Web as well as in hard copy.

One objective of the new program will be to help strengthen the nuclear science infrastructure in America. To accomplish this, graduate thesis projects related to the program objectives will be sponsored at many universities. Another objective will be to strengthen nuclear test facilities, and an Accelerator Driven Test Facility is under active consideration. The need to make better use of limited test facilities throughout the world is also one of the reasons why DOE will be seeking to increase international ADS/ATW collaboration. The coming years may see a considerable expansion of the international quest for effective transmutation systems.

Russia

Several research institutes in Russia are involved in a P&T programme directed by MINATOM. Most of the activities relevant to ADS are carried out within the framework of ISTC projects. The main research institutes involved in R&D in the field of ADS are: Institute of Theoretical and Experimental Physics (ITEP), Institute for Physics and Power Engineering (IPPE), All-Russian Scientific Research Institute of Experimental Physics (VNIIEF), Joint Institute of Nuclear Research

(JINR), Institute of Nuclear Energy (IAE), Institute of Nuclear Research of the Russian Academy of Sciences (INR RAS), Experimental Design Bureau GIDROPRESS (OKB GP), and the Petersburg Nuclear Physics Institute (PNPI). The main activities performed are: theoretical research, accumulation of experimental data for the justification of the physical processes in ADS, and design studies on ADS and its sub-systems.

European Commission

The Fifth Framework Programme (1998-2002) of the European Atomic Energy Community (EURATOM) has two specific programmes on nuclear energy, one for indirect research and training actions and the other for direct actions with the Joint Research Centre of the European Commission. The first one, "Research and training programme in the field of nuclear energy", includes a key action on nuclear fission and comprises four areas: (i) operational safety of existing installations; (ii) safety of the fuel cycle; (iii) safety and efficiency of future systems and (iv) radiation protection. In the safety of the fuel cycle, waste and spent fuel management and disposal, and partitioning and transmutation (P&T) are two large activities, whereas the decommissioning of nuclear installations is a smaller one.

To implement the key action on nuclear fission and the generic research on radiological sciences, a first call for proposals was made in 1999. In the area of partitioning and transmutation, 20 proposals were received, requesting about 3.8 times more than the available budget. By taking due account of the advice of the evaluators, the Commission services selected 10 proposals for funding at a level lower than requested due to budget limitations.

The selected projects are subdivided into three clusters: (i) partitioning, (ii) transmutation – technological support and (iii) transmutation – basic studies. The cluster on partitioning includes three projects. The first one on pyrometallurgical processing assesses salt/metal extraction and electrorefining for the separation of actinides and lanthanides, while the two others will develop aqueous processes for the chemical separation of minor actinides from high level waste. In the cluster on technological support, four projects will address (i) experimental work on neutron and proton irradiation damage to a spallation target, (ii) corrosion of structural materials by lead alloys used as a spallation target and as a coolant for an accelerator-driven system (ADS) and thermal hydraulic experiments with liquid lead alloys, (iii) fuel issues for ADS (fabrication and irradiation of nitride fuel) and (iv) irradiation of thorium fuel. Finally, three projects are grouped in the cluster on basic studies: one on the experimental investigation and code interpretation of sub-critical neutronics and two on nuclear data, one at medium and high energy required for the ADS engineering design including the spallation target, and one encompassing the lower energy in resonance regions required for transmutation.

Extended Technical Working Group (TWG)

In 1998, the Research Ministers of France, Italy and Spain, recognising the potentialities of Accelerator-Driven System (ADS) for the transmutation of long lived waste, had decided to set up a Group of Advisors (Ministers' Advisors Group – MAG) in order to define a common R&D European platform on ADS. On its meeting on May 1998, the MAG recommended a European demonstration programme over a 10-year time scale. A Technical Working Group (TWG) under the chairmanship of Prof. C. Rubbia was established with the task of identifying the critical technical issues in which R&D is needed, in view of a demonstration programme. In October 1998, the TWG issued an Interim Report [3] which, in particular, highlighted:

- The need of a demonstrator.
- The basic components and the different options for the proposed DEMO facility.

- The R&D directly relevant to the realisation of the demonstrator.

This report was endorsed by the MAG on its meeting of March 1, 1999 and, in the same context, the following main issues were brought forward:

- Extension of the European participation beyond the three countries initiative.
- Role of ADS transmutation R&D within the Fifth European Framework Programme.
- Recognition of the ASAP (As soon as possible)-DEMO as a European goal.

As a consequence, a MAG "ad hoc" meeting open to all the interested EU member states was held in Rome on April 21, 1999. Representatives of eleven countries (Austria, Belgium, Denmark, Finland, France, Germany, Italy, Portugal, UK, Spain and Sweden) participated in that meeting which gave rise to the following main conclusions:

- It was agreed that transmutation represents an attractive approach to radioactive waste disposal, being complementary to geological disposal.

- All participants appreciated the proposal to extend the participation in the initiative to other European countries besides France, Italy and Spain, particularly considering that similar approaches were being undertaken in the USA and Japan.

- The interim report of the TWG issued in 1998 was accepted as a good basis for future work to be carried out by an Extended (actually European) Technical Working Group (ETWG), under the chairmanship of Prof. C. Rubbia.

In September 1999, the ETWG – composed by representatives of Austria, Belgium, Finland, France, Germany, Italy and Spain – issued a new technical report [4] aimed at providing an overview of the different ongoing activities on ADS in various European countries, along with an examination of the proposals to be submitted to the Fifth FWP. The report, presented to and endorsed by MAG on its meeting of September 17, 1999, also identified a number of open points and gave recommendations for the future development of the activities. In particular, the ETWG strongly recommended an increased support – even by European Commission – and co-ordination of ADS-related activities at multinational level.

Early 2000, the ETWG (further enlarged to representatives of JRCs, Portugal and Sweden), issued a so-called four-page document [5] on strategy of implementation of the ADS programme in Europe. In particular, the document calls for the urgent definition of a "roadmap" towards demonstration of feasibility of an European waste transmutation facility and recognises its potentially-relevant implications on the 6^{th} European Framework Programme. The four-page document was submitted to the MAG at its last meeting on February 25, 2000 and received positive comments: consequently, the TWG was committed and encouraged by MAG to proceed in the forthcoming months in defining the above-mentioned roadmap.

The report, entitled "A European Roadmap for Developing Accelerator Driven Systems for Nuclear Waste Incineration" [6], was issued by the ETWG on April 2001.

After reviewing historical background and identifying motivations for developing ADS technology in the field of P&T, the Roadmap defines and proposes a detailed technical programme, comprehensive of planning and cost estimates, which will lead to the construction of an Experimental ADS (XADS) within 12 years, covering the 6^{th} and 7^{th} European Framework Programmes. This is considered, by the ETWG, as an essential prerequisite to assess the safe and efficient behaviour of such systems for a large-scale deployment for transmutation purposes in the first half of this century.

The document also reviews and assesses the status of current scientific and technology programmes and facilities relevant to ADS research in the EU and worldwide, and – by means of three specific reports - presents a comprehensive overview of the status and future developments in the field of high-power proton accelerators [7] and innovative fuels and reprocessing technology [8,9].

At last, the Roadmap identifies possible synergies that the ADS programme could have within the scientific community, indicates potential spin-offs, shows how competence can be maintained in the currently stagnating field of nuclear energy research.

As a result of a mandate given to the ETWG, the Roadmap was directed, in the first instance, to MAG on May 2001. The document – being of interest, however, to policy makers throughout Europe – was also addressed on July 2001 to members of the European Parliament, to the relevant Directorates General of the European Union, as well as to national and international organisations involved with ADS research and development within the EU and worldwide.

IAEA

In compliance with its statutory mandate, one of IAEA's roles is to provide all Member States with an international source of balanced and objective information on advances in nuclear technology, and to provide an international forum for information exchange and co-operative research.

Accelerator-driven transmutation of long-lived waste has increasingly become of interest in many Member States, and could be an important component of strategies to deal with international requirements in managing nuclear materials.

To respond to the Member States' needs, the IAEA has established the project on "Technology Advances in Fast Reactors and Accelerator Driven Systems for Actinide and Long-lived Fission Product Transmutation" [10].

Within the framework of this project, a status report "Accelerator-driven Systems: Energy Generation and Transmutation of Nuclear Waste" [11] was published, providing an overview of ongoing development activities, different concepts being developed and their status, as well as typical development trends in this area, and evaluating the potential of these systems for power production, plutonium incineration and transmutation of minor actinides and long-lived fission products. It is intended to update this status report at regular intervals, and establish it as a "living document" on the project's Web Site [10].

Among the most important collaborative R&D activities of the project, mention must be made of the "Coordinated Research Project (CRP) on the Use of Thorium-based Fuel Cycles in Accelerator Driven Systems (ADS) to Incinerate Plutonium and to Reduce Long-term Waste Toxicities", concluded at the end of 2000 [12]. The last stage of this CRP was centered on experimental benchmarks based on the YALINA experiments (a sub-critical, thermal facility set up in Minsk, Belarus in the frame of ISTC project #B070). It is planned to start in 2002 a follow-up CRP on "Benchmark Analyses on Data and Calculational Methods for Accelerator-driven System (ADS) Source Related Neutronic Phenomenology with Experimental Validation", addressing all major physics phenomena of the spallation source and its coupling to the sub-critical system. The participants will apply integrated calculation schemes to perform computational and experimental benchmark analyses. Also to start in 2002, the CRP on "Studies of Advanced Reactor Technology Options for Effective Incineration of Radioactive Waste" will focus, in its first stage, on analyses of safety-relevant parameters of ADS. The main thrust will be on long time-scale effects of transients initiated by strong perturbations of the neutron source or of the sub-critical core. Benchmark models based on various designs of the sub-critical core, as well as extreme cases (sub-critical cores "dedicated" to transmutation, i.e. fuelled with transuranics in a fertile-free matrix) will be considered. This CRP will also seek to perform experimental benchmark studies.

Last but not least, an important ongoing activity is to implement a "Database of Experimental Facilities and Computer Codes for ADS Related R&D" (so called "ADS R&D Database"). Presently, a WWW-based version of the database is being tested in-house and will be operational shortly [10].

OECD/NEA

Back in 1989, the OECD/NEA started a comprehensive programme of work in the field of partitioning and transmutation (P&T) [13]. This programme was initiated by a request from the Japanese government which was launching a programme on P&T (OMEGA project) and invited the OECD/NEA to co-ordinate an international information exchange programme on P&T. This has since materialised in several activities, among them the Information Exchange Meetings and state-of-the-art systems studies besides a diverse set of activities oriented towards more basic science. NEA has recently reorganised the P&T activities as a horizontal project between the Nuclear Development and Nuclear Science Committees, and while a restructuring of the science programme under the umbrella of a new Working Party on Scientific Issues in P&T, covering specifically ADS aspects, has recently been started. This Working Party will envelop the scientific aspects of P&T and comprises four sub-groups:

- Group on Accelerator Utilisation and Reliability:

  This group emerges from previous workshops on Accelerator Utilisation and Reliability, will synthesise the improvements made and draw conclusions from each workshop held and continue to organise such workshops. The group will also deal with target and window performances, for instance, issues on spallation products and thermal stress and radiation damage, respectively.

- Group on Chemical Partitioning:

  The existing expert group on Pyrochemistry moves under this WPPT and will first focus on drafting a state-of-the-art report on Pyrochemistry. Despite its name, the group will also look into aqueous processing issues.

- Group on Fuels and Materials, as the new proposed transmutation systems will demand specific materials to be validated or developed for use in more challenging irradiation conditions.

- Group on Physics and Safety of Transmutations Systems:

This group will organise theoretical and experiment-based benchmarks to validate nuclear data as well as calculation tools needed for simulating advanced transmutation systems, and investigate safety aspects of transmutation systems such as the beam trip problem of ADS.

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