PARTITIONING AND TRANSMUTATION IN THE EURATOM FIFTH FRAMEWORK PROGRAMME

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Abstract

Partitioning and Transmutation (P&T) of long-lived radionuclides in nuclear waste is one of the research areas of the EURATOM Fifth Framework Programme (FP5) (1998-2002). The objective of the research work carried out under FP5 is to provide a basis for evaluating the practicability, on an industrial scale, of P&T for reducing the amount of long lived radionuclides to be disposed of. The content and the implementation of the EURATOM FP5 are briefly presented. The research projects on P&T selected for funding after the first call for proposals are then briefly described. They address the chemical separation of long-lived radionuclides and the acquisition of technological and basic data, necessary for the development of an accelerator driven system. Other projects are expected in response to the next call with a deadline in January 2001. International co-operation in P&T should be fostered. Collaboration is being implemented in this field between scientists of the European Union (EU) and the Commonwealth of Independent States (CIS). Finally, a brief outline of the discussions for the preparation of the Sixth Framework Programme (2002-2006) is given.

1. Introduction

The priorities for the European Union's research and development activities for the period 1998-2002 are set out in the Fifth Framework Programme (FP5). These priorities have been identified on the basis of a set of common criteria reflecting the major concerns of increasing industrial competitiveness and the quality of life for European citizens. FP5 has been conceived to help solve problems and to respond to major socio-economic challenges facing Europe. To maximise its impact, it focuses on a limited number of research areas combining technological, industrial, economic, social and cultural aspects.

The Fifth Framework Programme has two distinct parts: the European Community Framework Programme covering research, technological development and demonstration activities; and the EURATOM Framework Programme covering research and training activities (RT) in the nuclear field.

The content and the implementation of the latter are briefly presented in this paper.

Partitioning and Transmutation (P&T) of long-lived radionuclides in nuclear waste is one of the research areas of the EURATOM FP5. This paper briefly recalls the goals of P&T, its position in the framework of nuclear waste management and disposal and its renewed interest worldwide. The research projects on P&T so far selected for funding in FP5 are then briefly described. Co-operation in this field with some countries of the Commonwealth of Independent States (CIS) through the International Science and Technology Centre in Moscow is also outlined.

Finally, some indications are given concerning the European Union's research beyond the Fifth Framework Programme and the "European Research Area".

2. The EURATOM Fifth Framework Programme (FP5) (1998-2002)

The Fifth Framework Programme of the European Atomic Energy Community (EURATOM) has two specific programmes on nuclear energy, one for indirect research and training actions managed by the Research Directorate General (DG RTD) and the other for direct actions under the responsibility of the Joint Research Centre of the European Commission (EC). The strategic goal of the first one, "Research and training programme in the field of nuclear energy", is to help exploit the full potential of nuclear energy in a sustainable manner, by making current technologies even safer and more economical and by exploring promising new concepts [1]. This programme includes a key action on controlled thermonuclear fusion, a key action on nuclear fission, research and technological development (RTD) activities of a generic nature on radiological sciences, support for research infrastructure, training and accompanying measures. The key action on nuclear fission and the RTD activities of a generic nature are being implemented through indirect actions, i.e. research co-sponsored (up to 50% of total costs) and co-ordinated by DG RTD, but carried out by external public and private organisations as multi-partner projects. The total budget available for these indirect actions during FP5 is 191 millions €.

The key action on nuclear fission 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. The operational safety of existing installations deals with plant life extension and management, severe accident management and evolutionary concepts. In the safety of the fuel cycle, waste and spent fuel management and disposal, and partitioning and transmutation are the two larger activities, as compared to the decommissioning of nuclear installations. The objective of safety and efficiency of future systems is to investigate and assess new or revisited concepts for nuclear energy,

that would be more economical, safer and more sustainable in terms of waste management, utilisation of fissile material and safeguards. Radiation protection has four sub-areas: (i) risk assessment and management, (ii) monitoring and assessment of occupational exposure, (iii) off-site emergency management and (iv) restoration and long-term management of contaminated environments.

The implementation of the key action on nuclear fission is made through targeted calls for proposals with fixed deadlines. The generic research on radiological sciences is the subject of a continuously open call, but proposals are evaluated in batches. Following the calls for proposals made in 1999, about 140 proposals covering all areas of the key action and of the generic research have been accepted for a total funding of around 100 million €. Most of the projects have started now. A new call for proposals has been made on 16 October 2000 with a deadline on 22 January 2001 to select proposals for another 50 million €. The 2000 version of the Work Programme is available on the CORDIS website (www.cordis.lu/fp5-euratom). A final call will be made in October 2001.

3. Partitioning and Transmutation (P&T)

Spent fuel and high level waste contain a large number of radionuclides from short-lived to long-lived ones, thus requiring very long time periods to be considered for their geological disposal. The long-lived radionuclides are mainly the actinides and some fission products. Partitioning and Transmutation aims at reducing the inventories of long-lived radionuclides in radioactive waste by transmuting them into radionuclides with a shorter lifetime [2].

Partitioning is the set of chemical and/or metallurgical processes necessary to separate from the high-level waste the long-lived radionuclides to be transmuted. This separation must be very efficient to obtain a high decontamination of the nuclear waste. It should also be very selective to achieve an efficient transmutation of the long-lived radiotoxic elements.

Long-lived radionuclides could be transmuted into stable or short-lived nuclides in dedicated burners. These burners could be critical nuclear reactors and sub-critical reactors coupled to accelerators, the so-called accelerator-driven systems (ADS).

If successfully achieved, P&T will produce waste with a shorter lifetime. However, as the efficiency of P&T is not 100%, some long-lived radionuclides will remain in the waste, which will have to be disposed of in a deep geological repository. P&T is still at the research and development (R&D) stage. Nevertheless, it is generally accepted that the techniques used to implement P&T could alleviate the problems linked to waste disposal.

There has been a renewal of interest in P&T worldwide at the end of the eighties (OMEGA programme in Japan, SPIN programme in France). Meanwhile, sufficient progress has been made in accelerator technology to consider as feasible the use of ADS for waste incineration. Proposals to develop ADS have been made during the nineties by the Los Alamos National Laboratory in the USA with the ATW (Accelerator driven Transmutation of Waste) programme, by CERN in Europe with the Energy Amplifier (EA) [3] and by JAERI in Japan. In addition, there is a number of research activities on ADS going on in several EU countries (Belgium, France, Germany, Italy, Spain, Sweden), Czech Republic, Switzerland, Republic of Korea and Russian Federation.

The interest for P&T in the EU is reflected in the increase of funding in this area over the EURATOM Framework Programmes, 4.8, 5.8 and about 26 million € for the Third, Fourth and Fifth Framework Programmes respectively.

In the EURATOM Fourth Framework Programme (1994-1998), there were research activities on P&T covering three aspects: (i) strategy studies, (ii) partitioning techniques, (iii) transmutation techniques. The progress achieved in the field of partitioning of minor actinides by aqueous processes suggested that, with some additional effort, a one-cycle process for the direct extraction of minor actinides from liquid high-level waste could be demonstrated at the pilot plant scale. The conclusions of the P&T strategy studies concerning critical and sub-critical reactors and the results obtained in the transmutation experiments clearly indicated that the feasibility of ADS should be more thoroughly investigated for transmutation of nuclear waste [4].

4. The research activities on P&T in the EURATOM Fifth Framework Programme

The objective of the research work carried out under FP5 is to provide a basis for evaluating the practicability, on an industrial scale, of partitioning and transmutation for reducing the amount of long lived radionuclides to be disposed of.

After the first call for proposals in 1999, 19 proposals were received in the area of partitioning and transmutation, requesting about 3.8 times more than the available budget. By taking due account of the advice of the evaluators, the Commission services selected 9 proposals for funding at a level lower than requested due to budget limitations. All the projects have already started between August and November 2000.

The selected projects address different scientific and technical aspects of P&T and have therefore been grouped in three clusters. The experimental investigation of efficient hydro-metallurgical and pyrochemical processes for the chemical separation of long-lived radionuclides from liquid high-level waste is carried out in the cluster on partitioning. The work on transmutation is mainly related to the acquisition of data, both technological and basic, necessary for the development of ADS. The cluster on transmutation – technological support – deals with the investigation of radiation damage induced by spallation reactions in materials, of the corrosion of structural materials by lead alloys and of fuels and targets for actinide incineration. In the cluster on transmutation – basic studies, basic nuclear data for transmutation and ADS engineering design are collected and sub-critical neutronics is investigated.

The cluster on partitioning includes three projects, the main characteristics of which are given in Table 1. The first one, **PYROREP**, aims at assessing flow sheets for pyrometallurgical processing of spent fuels and targets. Two methods, salt/metal extraction and electrorefining, will investigate the possibility of separating actinides from lanthanides. Materials compatible with corrosive media at high temperature will be selected and tested. It is worth noting that one of the partners of this project is CRIEPI, the research organisation of the Japanese utilities.

The two other projects are dealing with the development of solvent extraction processes of minor actinides (americium and curium) from the acidic high level liquid waste (HLLW) issuing the reprocessing of spent nuclear fuel. In **PARTNEW**, the minor actinides are extracted in two steps. They are first co-extracted with the lanthanides from HLLW (DIAMEX processes), then separated from the lanthanides (SANEX processes). Basic studies will be performed for both steps, in particular synthesis of new ligands and experimental investigation and modelling of their extraction properties. The radiolytic and hydrolytic degradation of the solvents will be also studied and the processes will be tested with genuine HLLW.

The **CALIXPART** project is dealing with the synthesis of more innovative extractants. Functionalized organic compounds, such as calixarenes, will be synthesised with the aim of achieving the direct extraction of minor actinides from HLLW. The extracting capabilities of the new

compounds will be studied together with their stability under irradiation. The structures of the extracted species will be investigated by nuclear magnetic resonance (NMR) spectroscopy and X-ray diffraction to provide an input to the molecular modelling studies carried out to explain the complexation data.

Table 1. **Cluster on partitioning**

Acronym	Subject of research	Co-ordinator (country)	Number of partners	Duration (months)	EC funding (Million €)
PYROREP	Pyrometallurgical processing research	CEA (F)	7	36	1.5
PARTNEW	Solvent extraction processes for minor actinides (MA)	CEA (F)	10	36	2.2
CALIXPART	Selective extraction of MA by organised matrices	CEA (F)	9	36	1.3

The cluster on transmutation-technological support has four projects (see Table 2). The **SPIRE** project addresses the irradiation effects on an ADS spallation target. The effects of spallation products on the mechanical properties and microstructure of selected structural steels (e.g. martensitic steels) will be investigated by ion beam irradiation and neutron irradiation in reactors (HFR in Petten, BR2 in Mol and BOR 60 in Dimitrovgrad). Finally, data representative of mixed proton/neutron irradiation will be obtained from the analysis of the SINQ spallation target at the Paul Scherrer Institute in Villigen.

The objective of **TECLA** is to assess the use of lead alloys both as a spallation target and as a coolant for an ADS. Three main topics are addressed: corrosion of structural materials by lead alloys, protection of structural materials and physico-chemistry and technology of liquid lead alloys. A preliminary assessment of the combined effects of proton/neutron irradiation and liquid metal corrosion will be done. Thermal-hydraulic experiments will be carried out together with numerical computational tool development.

Fuel issues for ADS are addressed in the **CONFIRM** project. Computer simulation of uranium free nitride fuel irradiation up to about 20% burn-up will be made to optimise pin and pellet designs. Other computations will be performed especially concerning the safety evaluation of nitride fuel. Plutonium zirconium nitride [(Pu, Zr)N] and americium zirconium nitride pellets will be fabricated and their thermal conductivity and stability at high temperature will be measured. (Pu, Zr)N pins of optimised design will be fabricated and irradiated in the Studsvik reactor at high linear power (≈70 kW/m) with a target burn-up of about 10%.

The objective of the project **THORIUM CYCLE** is to investigate the irradiation behaviour of thorium/plutonium (Th/Pu) fuel at high burn-up and to perform full core calculations for thorium-based fuel with a view to supplying key data related to plutonium and minor actinide burning. Two irradiation experiments will be carried out: (i) four targets of oxide fuel (Th/Pu, uranium/plutonium, uranium and thorium) will be fabricated, irradiated in HFR in Petten and characterised after irradiation; (ii) one Th/Pu oxide target will be also irradiated in KWO Obrigheim. Though this project was accepted for funding in the area of “safety and efficiency of future systems”, it has been grouped with the three previous projects in the cluster on transmutation-technological support for convenience, because it is related to fuel issues.

Table 2. **Cluster on transmutation-technological support**

Acronym	Subject of research	Co-ordinator (country)	Number of partners	Duration (months)	EC funding (Million €)
SPIRE	Effects of neutron and proton irradiation in steels	CEA (F)	10	48	2.3
TECLA	Materials and thermo-hydraulics for lead alloys	ENEA (I)	16	36	2.5
CONFIRM	Uranium free nitride fuel irradiation and modelling	KTH (S)	7	48	1.0
THORIUM CYCLE	Development of thorium cycle for PWR and ADS	NRG (NL)	7	48	1.2

Finally, three projects are grouped in the cluster on transmutation-basic studies (see Table 3). The **MUSE** project aims to provide validated analytical tools for sub-critical neutronics including recommended methods, data and a reference calculation tool for ADS study. The experiments will be carried out by coupling a pulsed neutron generator to the MASURCA facility loaded with different fast neutron multiplying sub-critical configurations. The configurations will have MOX fuel with various coolants (sodium, lead and gas). Cross-comparison of codes and data is foreseen. Experimental reactivity control techniques, related to sub-critical operation, will be developed.

The last two projects are dealing with nuclear data, one at medium and high energy required for the ADS engineering design including the spallation target **(HINDAS)**, and the other encompassing the lower energy in resonance regions required for transmutation **(n-TOF-ND-ADS)**.

The objective of the **HINDAS** project is to collect most of the nuclear data necessary for ADS application. This will be achieved by basic cross section measurements at different European facilities, nuclear model simulations and data evaluations in the 20-200 MeV energy region and beyond. Iron, lead and uranium have been chosen to have a representative coverage of the periodic table, of the different reaction mechanisms and, in the case of iron and lead, of the various materials used for ADS.

The **n-TOF-ND-ADS** project aims at the production, evaluation and dissemination of neutron cross sections for most of the radioisotopes (actinides and long-lived fission products) considered for transmutation in the energy range from 1 eV up to 250 MeV. The project is starting with the design and development of high performance detectors and fast data acquisition systems. Measurements will be carried out at the TOF facility at CERN, at the GELINA facility in Geel and using other neutron sources located at different EU laboratories. Finally, an integrated software environment will be developed at CERN for the storage, retrieval and processing of nuclear data in their various formats.

Table 3. **Cluster on transmutation-basic studies**

Acronym	Subject of research	Co-ordinator (country)	Number of Partners	Duration (months)	EC funding (Million €)
MUSE	Experiments for sub-critical neutronics validation	CEA (F)	13	36	2.0
HINDAS	High and intermediate energy nuclear data for ADS	UCL (B)	16	36	2.1
n-TOF-ND-ADS	ADS nuclear data	CERN	18	36	2.4

The second call for proposals has been published in October 2000 with a deadline in January 2001. This call has been targeted on the areas, which were not sufficiently well covered by the projects selected after the first call, such as preliminary engineering design studies for an ADS demonstrator and technological support. A new item, networking, has been included in this call. But the areas of chemical separation and basic studies are not included, as they were well covered in the first call.

5. ADS related research activities in the framework of the International Science and Technology Centre (ISTC)

The International Science and Technology Centre (ISTC) was established by an international agreement in November 1992 as a non-proliferation programme through science co-operation. It is an intergovernmental organisation grouping the European Union, Japan, the USA, Norway, the Republic of Korea, which are the funding parties, and some countries of the Commonwealth of Independent States (CIS): the Russian Federation, Armenia, Belarus, Georgia, Kazakhstan and Kyrgyzstan. The ISTC finances and monitors science and technology projects to ensure that the CIS scientists, especially those with expertise in developing weapons of mass destruction, are offered the opportunity to use their skills in the civilian fields.

A Contact Expert Group (CEG) on ADS related ISTC projects has been created in January 1998. Its main objectives are to review proposals in this field and to give recommendations for their funding to the ISTC Governing Board, to monitor the funded projects and to promote the possibilities of future or joint research projects through the ISTC. Five topics have been identified for the ADS related projects: (i) accelerator technology, (ii) basic nuclear and material data and neutronics of ADS, (iii) targets and materials, (iv) fuels related to ADS and (v) aqueous separation chemistry. Because the funding parties primarily respond to local scientific/political interests and pressure, it was decided in January 2000 to reorganise the CEG into “local” CEGs (EU, Japan, Republic of Korea and USA) with some inter-co-ordination between them. This inter-co-ordination should foster exchange of information between ISTC projects in the same field, even if they are supported by different funding parties.

The EU CEG should develop co-operation between ISTC and FP5 EU funded projects. In fact, collaboration has already started between EU scientists, not necessarily belonging to the CEG, and CIS research teams both in the preparation of ISTC proposals and in the follow-up of projects in some specific areas. Links with FP5 projects will be established, once the projects have actually started. An area where the co-operation between ISTC and FP5 EU funded projects could be improved is that of basic nuclear data for ADS.

6. Community research for the period 2002-2006

The Commissioner responsible for research in the EC launched the idea of a “European Research Area” in a communication [5] in January 2000. The intention is to contribute to the creation of better overall working conditions for research in Europe. The Communication is applicable to all areas of research. The starting point was that the situation concerning research in Europe is worrying, given the importance of research and development for future prosperity and competitiveness.

In October 2000, the Commission adopted a communication for the future of research in Europe, which sets out guidelines for implementing the “European Research Area” initiative, and more particularly the Research Framework Programme [6]. It is proposed to change the approach for the next Framework Programme, based on the following principles:

- Focusing on areas where Community action can provide the greatest possible “European added value” compared with national action.
- Closer partnership with the Member States, research institutes and companies in Europe by networking the main stakeholders.
- Greater efficiency by channelling resources to bigger projects of longer duration.

The Commission's proposals take account of the results of the evaluation of the previous Framework Programmes carried out by an Independent Expert Panel.

In practical terms, the following arrangements are proposed:

- Networking of national research programmes through support for the mutual opening-up of programmes and EU participation in programmes carried out in a co-ordinated fashion.
- Creation of European networks of excellence by networking existing capacities in the Member States around “joint programmes of activities”.
- Implementation of large targeted research programmes by consortia of companies, universities and research centres on the basis of overall financing plans.
- Greater backing for regional and national efforts in support of innovation and research conducted by small and medium enterprises (SME).
- More diversified action in support of research infrastructures of European interest.
- Increase in and diversification of mobility grants not only for EU researchers but also for researchers from third countries. Measures in respect of human resources in research are proposed, including the “Women and Science” Action Plan.
- Action to strengthen the social dimension of science, in particular in matters concerning ethics, public awareness of science and giving young people a taste for science.

At its meeting in November 2000, the Research Council supported the general approach of the Commission as set out in its communication aiming at the continuation of the implementation of the “European Research Area”. It further noted the importance of the Framework Programmes as strategic tools to achieve the creation of the “European Research Area” and to increase the efficiency of research activities in Europe. Finally, the Council invited the Commission to transmit to it formal proposals concerning the Sixth Framework Programme (FP6) (2002-2006) during the first quarter of 2001.

In view of the future research programme, the EURATOM Scientific and Technical Committee has prepared a report on the strategic issues to be considered in the development of the appropriate nuclear energy research strategies in a 20-50 year perspective [7]. The main message is that "a key R&D objective should be to ensure that future generations have a real selection of available technologies to choose from when they have to decide on the energy supply system that would best suit their needs and acceptance criteria. Therefore, R&D on technical options with a capacity to contribute significantly to base-load electricity supply must be carried out, including the fission and fusion options." They also stress that, given the increased competition in the deregulated electricity market, public financing will be increasingly needed to ensure that society maintains and develops the scientific and technical infrastructure needed as a basis for long-term industrial development and competitiveness. In the area of nuclear fission, continued support should be given to maintain and develop the competence needed to ensure the safety of existing and future reactors. In addition, support should be given to explore the potential for improving present fission technology from a sustainable development point of view (better use of uranium and other nuclear fuels, whilst reducing the amount of long-lived radioactive waste produced).

The detailed discussions about the content of FP6 have now started.

7. Conclusion

The research activities in the field of partitioning and transmutation under the EURATOM Fifth Framework Programme have now begun. At present, the research projects are addressing the chemical separation of long-lived radionuclides and the acquisition of technological and basic data, necessary for the development of an accelerator-driven system. Other projects are expected for the next call for proposals with a deadline in January 2001. This call is targeted on the areas, which were not sufficiently well covered by the projects selected after the first call, such as preliminary engineering design studies of an ADS demonstrator, technological support and networking. Both, the present projects and those, which will be selected next year, should contribute significantly to providing a basis for evaluating the practicability, on an industrial scale, of partitioning and transmutation for reducing the amount of long lived radionuclides to be disposed of.

Concerning international co-operation, a Japanese research organisation is already participating in one of the FP5 projects without EU funding. The EU Contact Expert Group on ADS is fostering collaboration between EU and CIS research teams by linking FP5 and ISTC EU funded projects, which are related to ADS. It is hoped that co-operation in the field of partitioning and transmutation will be extended to other countries in the near future.

The discussions about the scientific content of the Sixth Framework Programme (FP6) (2002-2006) have just started. FP6 is a strategic tool to achieve the creation of the "European Research Area", an idea which was launched by the Commissioner responsible for research in January 2000.

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