THE EU RESEARCH ACTIVITIES ON PARTITIONING AND TRANSMUTATION: FROM THE 4TH TO THE 5TH FRAMEWORK PROGRAMME

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Abstract

The European Commission is partly supporting research work on partitioning and transmutation of radioactive waste under the Fourth Framework Programme (1994-1998). This work includes nine research projects. Five strategy studies are evaluating the capabilities of various burners and fuel cycles to limit the production and even destroy the stock of actinides (plutonium and minor actinides). Two experimental projects are aiming at developing techniques for the chemical separation of actinides and two others are dealing with the investigation of transmutation of americium and long-lived fission products. The objectives of these studies are described together with the main results already obtained. The European Union should adopt the 5th Framework Programme (1998-2002) at the end of 1998. The broad lines of the research activities foreseen in partitioning and transmutation and future systems under the 5th Framework Programme are briefly presented.

Introduction

The European Union has launched in 1994 a specific programme on Nuclear Fission Safety in the Framework Programme for the European Atomic Energy Community (1994-1998). This specific programme covers research activities on reactor safety, radioactive waste management and disposal and radiation protection. It includes in particular research work on partitioning and transmutation (P&T) which is divided in three research tasks: strategy studies, partitioning techniques and transmutation techniques. Nine projects are covering these tasks with five in the field of strategy studies, two in partitioning techniques and two in transmutation techniques. They involve different European research organisations, which are partly funded by the European Commission. This paper presents the objectives of these projects and summarises the main results obtained so far.

The 5th Framework Programme (1998-2002) should be adopted by the European Union before the end of 1998. The specific programme for research and training in the field of Nuclear Energy includes activities on both controlled thermonuclear fusion and nuclear fission. In the field of nuclear fission, it is foreseen to increase the support to the research activities devoted to partitioning and transmutation and to open a new chapter on future systems. The future systems considered in the programme are in particular innovative or revisited concepts for reactors, fuels and fuel cycles. The content of the 5th Framework Programme and the broad lines of the activities on P&T and future systems are briefly presented in the paper.

Partitioning and Transmutation (P&T) under the 4th Euratom Framework Programme

The objectives of the nine research projects on P&T [1] are described together with the main results obtained so far [2,3]. These projects are five strategy studies on P&T (four shared-cost actions and one concerted action), two experimental investigations of partitioning techniques and two experimental studies of transmutation techniques. The strategy studies are aiming at assessing the capabilities of different burners and fuel cycles to limit the production or even destroy the stock of actinides (plutonium and minor actinides). The following order has been adopted to present the research projects in this section: first the both experimental studies of partitioning techniques, then three projects related to transmutation in reactors, followed by a study dealing with the thorium fuel cycle and finally three projects on accelerator-driven systems (ADS).

Experimental work on partitioning

New partitioning techniques (NEWPART)

CEA Marcoule is co-ordinating this project, which involves seven other partners: Reading University, Chalmers University in Göteborg, JRC-ITU Karlsruhe, ENEA Ispra, Univ. “Politecnico” Milano, FZK Karlsruhe and FZJ Jülich [4].

The objective of the project is to develop solvent extraction partitioning processes of minor actinides (mainly americium and curium) from the high level liquid waste (HLLW) generated by spent fuel reprocessing using the PUREX process. Because of the difficulty of the problem, the partitioning process is based on two extraction cycles. The first cycle consists in the co-extraction of actinides and lanthanides from the HLLW using malonamides as extractants (DIAMEX process). The second cycle aims at separating the actinides from the lanthanides. Several extraction systems are being investigated: (i) nitrogen polydentate ligands; (ii) sulphur bearing extractants; (iii) synergistic combination of (i) or (ii) with other chemical compounds.

Progress has been made in the comprehension of the basic chemical reactions between malonamide extractants and trivalent actinide and lanthanide nitrates. This could be achieved thanks to crystal structure determinations, X-ray absorption spectroscopy and molecular modelling. In addition, several flowsheets using different malonamides have been designed and tested to further develop the DIAMEX process. Active tests of these new flowsheets will be carried out shortly.

Concerning the separation between actinides and lanthanides, new nitrogen polydentate ligands have been synthesised and tested, which exhibit outstanding selective extraction properties for actinides. In particular, the pyridine-bis-1,2,4-tri-azines are able to selectively extract actinides from lanthanides in 1 to 2 molar nitric acid solutions. A synergistic mixture of newly synthesised sulphur bearing extractants and TOPO has enabled to obtain an effective separation between actinides and lanthanides in a 0.5 molar nitric acid solution during a counter-current test in a bank of centrifugal contactors [5].

The results obtained in the framework of this project suggest that it might be possible in a near future to develop a process with a single cycle allowing the direct extraction of the minor actinides from the very acidic HLLW.

Extraction and selective separation of long lived nuclides by fonctionalized macrocycles

This research project involves CEA Cadarache as co-ordinator and eight European universities (ECPM Strasbourg, Univ. Mainz, Univ. Parma, Univ. Twente, Univ. L. Pasteur in Strasbourg, Univ. Valencia, Univ. Liège, Univ. Autónoma in Madrid).

The objectives of the project are to synthesise and test macrocyclic compounds for the selective extraction of radionuclides with two purposes:

- Decategorisation of waste by selective removal of strontium and actinides.
- Separation of trivalent actinides from lanthanides.

Five of the universities have been synthesising a large number of extractants (mainly calixarene and bis-crown ether derivatives) for the removal of strontium, actinides and the separation between actinides and lanthanides. After testing these compounds, the most promising ones are described in what follows.

Strontium complexation and extraction experiments indicate that methyloxy and octyloxy calix[8]arene octa diethyl amide are good extractants for strontium from acidic medium with a high selectivity with respect to sodium.

Calix[4]arenes bearing acetamido phosphine moieties on the wide rim or “wide rim CMPO like calixarenes” have an excellent complexing and extracting ability with lanthanides and actinides in very acidic solutions, much larger than that of CMPO used at a concentration 250 times higher. In addition, the “wide rim CMPO like calixarenes” allow lanthanides to be discriminated and actinides to be separated from the heaviest lanthanides.

The crystal structure of two complexes of strontium with the p-tertbutylcalix[8]arene octaamide and the p-methoxycalix[8]arene has been determined by X-ray diffraction. It indicates that two strontium cations are inside the cavity of the calixarene. In addition, the behaviour in solution of several lanthanide and actinide complexes with different calixarenes has been studied by NMR.

Quantum mechanics calculations have been performed to understand the selective complexation of the cations with the extractants. In particular, the comparison between the interaction energies for several complexes of cations with alkyl (or phenyl) phosphine oxide indicates the crucial role of phenyl groups compared to alkyl groups, to enhance the interactions with lanthanides and to discriminate between them.

Transmutation in reactors

Evaluation of possible P&T strategies and of associated means to perform them

This project is co-ordinated by CEA Marcoule and involves ten other European laboratories (FZK Karlsruhe, AEA Technology Harwell, BNFL Risley, Belgonucléaire Brussels, SCK•CEN Mol, NRG Petten, JRC-ITU Karlsruhe, GRS Köln, ENEA Roma, Univ. "Politecnico" Milano).

The aim of this study is to give indications on what can be expected from partitioning and transmutation (P&T) strategies. The project includes five work packages: (WP1) global evaluation of different P&T scenarios and assessment of (WP2) partitioning techniques, (WP3) the feasibility of transmutation, (WP4) advanced fuel or target fabrication and (WP5) geological barrier efficiency.

The five scenarios investigated in WP1 are: (1) "once-through" cycle; (2) implementation of P&T with Highly Moderated Pressurised Water Reactors (HM-PWRs); (3) implementation of P&T with CAPRA type Fast Neutron Reactors (FNRs); when equilibrium is reached for scenario (3), it can be followed by either (4) a progressive introduction of EFR type FNRs or (5) a gradual decrease of nuclear power. Recycling of plutonium (Pu) and minor actinides is implemented after a 40-year period during which Pu is only recycled once in current MOX-fuelled PWRs. The total installed electric power remains fixed at 120 GWe.

The evaluation of the feasibility of transmutation indicates that HM-PWR cores could consume a significant amount of plutonium with a moderator-to-fuel ratio of about 4, but that the safety of such cores seems doubtful in view of the present requirements. However, the simulation of Scenario 2 shows an impossibility to recycle both plutonium and minor actinides with only HM-PWRs. In the case of CAPRA burners (Scenario 3), the envisaged recycling of actinides seems quite feasible from the reactor standpoint. The scenario evaluation confirmed that mining and milling and reactor operation were the main sources of short-term risk to the public in the fuel cycle. The risk is smaller for Scenario 3 than for Scenario 1, as the additional risk due to reprocessing operations is largely compensated by the decrease of mining activities.

In WP5, three geological host formations in which the waste resulting from the P&T scenarios would be disposed of have been evaluated on the basis of specific sites (Mol for clay, Gorleben for salt) and a generic site (granite). Normal evolution and human intrusion scenarios have been considered for geological disposal. It turns out that the waste from Scenarios 1, 3, 4 and 5 only have a minor effect on the normal evolution scenario, and that the doses are acceptable even in the case of direct disposal of spent fuel. To obtain a large reduction of the dose, long-lived fission products need to be transmuted, but this is difficult for technical and scientific reasons. The effects of P&T implementation on the consequences of the human intrusion scenario are only important if the efficiency of partitioning is very high and if it is possible to transmute most of the inventory of all actinides including curium [6].

Preliminary assessments of PUREX-based and pyro-metallurgical reprocessing techniques applied to CAPRA fuels were performed (WP2). For the PUREX process, the main issue is the dissolution of fuel containing high plutonium concentration in nitric acid for which experimental data are expected. Concerning the pyro-metallurgical process, developed at Argonne National Laboratory, the oxide-to-metal conversion required for its implementation seems possible, but the influence of the accumulation of fission products in molten salt during recycling needs further assessments.

Three processes for fabrication of fuels and targets containing minor actinides have been investigated in WP4. The MIMAS process (powder blending) could be used without significant difficulties for this purpose. The sol-gel precipitation process could be safer (it produces less dust) and better for recycling (more homogeneous U-Pu mixture). Impregnation techniques tested in the framework of the EFTTRA programme proved to be suitable for target fabrication (see below).

Supporting nuclear data for advanced MOX fuels

Belgonucléaire Brussels co-ordinates this study, which involves five other European partners (NRG Petten, SCK•CEN Mol, CEA Cadarache, JRC-ITU Karlsruhe, ENEA Bologna).

Its objective is to provide more accurate nuclear data for the P&T scenarios aiming at reducing the waste toxicity investigated in the strategy study described above. The use of advanced MOX fuels, either in PWRs or in FNRs, is studied. The necessary nuclear data working libraries are updated with new information from basic data evaluations and available integral experiments. The accuracy of the strategy studies to minimise wastes will be assessed at the end of the study.

Since the beginning of the project, a comprehensive compilation of irradiation results for high burn-up fuels has been carried out and experiments have been recalculated with modern computer codes and data sets.

The analysis of the composition of MOX fuels after irradiation at high burn-up (80 GWd/t in the highly moderated reactor BR3 in Mol and up to 46 GWd/t in the Saint Laurent B1 reactor) provides the experimental basis for PWRs. The values measured for the isotopic masses in the discharged fuel are being compared with the recalculated ones. Fairly good agreement is being found. In addition, the assessment of modelling errors has been completed.

In the case of the analysis of irradiation in FNRs, work has been progressing well. The comparison of computed and measured values for Phénix irradiations (PROFIL experiment) has been completed. Concerning the irradiations in KNK II in Karlsruhe, the chemical analysis of the fuel pins has been also completed and that of the single nuclide samples has started.

Joint EFTTRA experiment on americium transmutation

The objective of the project is to study the transmutation of ^{241}Am embedded in an inert matrix (spinel) in an irradiation experiment in the High Flux Reactor (HFR) at Petten. It includes the fabrication of a target pin, the execution of irradiation, post-irradiation examinations (non-destructive and destructive) and the interpretation of the results [7].

The work is being performed by the EFTTRA group, a collaboration of laboratories and research institutes in Europe (CEA and EDF in France, FZK in Germany, NRG in the Netherlands and ITU and IAM of the JRC of the European Commission).

The project is progressing according to plan. The irradiation of the target in HFR and the non-destructive post-irradiation examinations have been completed. The destructive examinations will be carried out by ITU soon.

The target contained 10 pellets of spinel (aluminium-magnesium oxide) with 11.5% in weight of americium oxide (about 0.7g of americium in total) in a titanium steel alloy cladding. It has been irradiated for 359 days in HFR, which represents a fluency of $1.7 \times 10^{26} m^{-2}$ for neutrons with an energy above 100 keV.

The first non-destructive post-irradiation examinations indicate that:

– the distribution of americium is not homogeneous inside the pellets; there is more americium at the edge of the pellet than inside; this is due to the impregnation technique used to fabricate the pellet;

– the pellets have swollen in volume by 15 to 18%, which is too much compared to a swelling of about 3% for uranium oxide; the swelling is caused by the alteration of the spinel matrix by the fission products.

The results of the calculations of the radial and axial transmutation effects can be summarised as follows:

– the flux profile is flat in the vertical direction;

– 92.3% of americium has been transmuted;

– the total content of actinides in the sample has decreased by 32%;

– the shielding effect leads to a higher transmutation rate for americium at the outer region of the pellets than at the inner region.

Thorium cycles as a nuclear waste management option

This project is co-ordinated by NRG Petten. Six other European laboratories are participating to this study: CNRS Orsay, Belgonucléaire Brussels, CEA Cadarache, FZJ Jülich, JRC-ITU Karlsruhe, ENEA Roma.

The goal of the project is an assessment of thorium cycles with a view to limit nuclear waste production and to burn waste, keeping in mind that thorium will be, in any case, a long-term option. The major fuel cycle steps have to be reviewed, focused on the European situation with thorium fuelled PWRs and FNRs as candidate reactors. The case of one thorium fuelled hybrid system is also investigated.

The six work packages of the project are covering the different steps of the thorium (Th) fuel cycle. The results obtained so far can be summarised as follows.

From the study of "Mining" (WP1), it appears that the thorium cycle leads to less mining waste production than the uranium cycle and that the waste could be disposed of in geological formations, which is not possible in practice for uranium waste. The final extracted thorium oxide product, however, has a higher gamma ray, alpha dose and radiotoxicity than uranium oxide.

"Fabrication of fresh thorium fuels" (WP2) does not lead to dose rates higher than those of conventional MOX fuel.

The study of "PWR (once-through) scenarios with Th/U fuel" (WP3.1) indicates that, compared to the reference low-enriched uranium scenario, the radiotoxicity is strongly reduced for the waste in all cases up to about 20 000 years, with best results for Th with highly enriched uranium at high burn up. For longer storage times, decay products of ^{233}U dominate. Recycling will be studied in the next phase. "Th-assisted (once-through) Pu-burning in PWRs" (WP3.2) is a very good option, since such cores can consume twice more TRU compared to U/Pu MOX. Recycling will be studied in the next phase. "Fast reactors with Th and full recycling of actinides" (WP3.3) offer excellent possibilities to burn Pu and to breed ^{233}U simultaneously. A self-sustaining core with Th/^{233}U is possible with very small void coefficient. Important waste radiotoxicity reductions are possible below 30 000 years. "Accelerator-driven fast reactors" (WP 3.4) loaded with Th/^{233}U are being studied; computational methods have been validated and nuclear data problems have been identified. Waste radiotoxicity with recycling of actinides will be studied in the next phase.

"Reprocessing" (WP4) using the single-cycle THOREX process can lead to U, Pu losses of 0.1% and to protactinium (Pa) losses of 1 to 2 %. High decontamination factors can also be reached for fission products. The pyrochemical method seems promising for Th fuel as well.

The "Residual risks of geological disposal" (WP5) were evaluated for once-through PWR scenarios with Th/^{233}U and Th/Pu fuels. The total dose of the actinides (most important ^{231}Pa) turned out to be rather small. In fact, long lived fission products (^{129}I, ^{135}Cs) gave the highest contribution, followed by activation products (^{59}Ni, ^{94}Nb). There was not much difference with U-based fuels.

Finally, a systematic approach has been developed to assess the "Technical aspects of non-proliferation" (WP6). Some concerns with respect to possible proliferation of ^{233}U in case of recycling and the misuse of accelerators were formulated.

Transmutation in accelerator-driven systems (ADS)

Impact of the accelerator-based technologies on nuclear fission safety (IABAT)

KTH Stockholm is co-ordinating this project, to which participate nine other European research institutions (CEA Cadarache, NRG Petten, FZJ Jülich, ENEA Roma, FZK Karlsruhe, JRC-ITU Karlsruhe, AEA Technology Harwell, Univ. Uppsala, Univ. Chalmers Göteborg).

The overall objective of the IABAT project is to make a European assessment of the possibilities of accelerator-driven hybrid reactor systems from the point of view of safe energy production, minimum waste production and transmutation capabilities. The work programme has three main items. The progress achieved in each of them is given in what follows.

In the first item "System and fuel cycle studies", different ADS systems are investigated with a wide range of parameters like: neutron spectra varying from thermal to fast neutrons, fuel form from solid through suspension in liquid lead to molten salt solutions. A lead-bismuth spallation target has been optimised by performing thermal hydraulic calculations and making a pre-conceptual design. A number of code packages is being developed, e.g. a burn-up module for Monte Carlo codes and a kinetic code for liquid and solid fuels. In addition, some theoretical studies of ADS dynamics are carried out to interpret the reactivity control and to develop a methodology for subcriticality control. Finally, the radiotoxicity and proliferation resistance of different fuel cycles for ADS (thorium based plutonium burners, LWR waste incinerators and minor actinide incinerators) are being assessed.

Concerning the second item "Assessment of the technology and cost of accelerators", the basic requirements for accelerators for transmutation (power and performance) have been formulated. Cost models for linear and circular accelerators have been developed. The linear accelerator cost model has been benchmarked against the European Spallation Source cost estimate. The cost model for circular accelerators will be completed shortly.

The third item deals with "Basic nuclear and material data". First experiments on ^{232}Th fast fission yields and ^{233}U fission yields have been performed at OSIRIS mass-separator facility in Sweden. Models are validated with experimental data for nuclear reactions on ^{208}Pb, ^{54,56} Fe and ^{90}Zr induced by neutrons and protons. The creation of a cross-section library for neutrons and protons in the (0-150 MeV) energy range has started with data for $^{204, 206, 207, 208}$ Pb, ^{232} Th and ^{238}U.

Finally, it is worth mentioning that the analysis of different conceptual designs points in the direction of fast spectrum and liquid lead (or lead/bismuth) cooling for ADS.

Neutron driven nuclear transmutation by adiabatic resonance crossing (TARC)

This project is carried out by CERN as co-ordinator, Univ. Autónoma in Madrid, CNRS Grenoble and the Universities of Athens and Thessaloniki [8].

The main aim of this project is to develop both theoretically and experimentally a new method, the adiabatic resonance crossing (ARC), which enables to enhance strongly the capture rate of neutrons by the radionuclides to be incinerated. The peak cross sections for neutron energies corresponding to the resonance region are much larger than for the other neutron energies. For instance, the cross section of ^{99}Tc is 4 000 barn at the peak of a resonance at 5 eV, but it is only 20 barn at thermal energy. Access to the resonance region can be achieved by using a transparent medium like lead where the neutrons lose their energy in very small decrements. Then, the neutron energy decreases slowly through the resonances, leading to very large probability of capture during crossing. An experimental test has been carried out on ^{99}Tc with a neutron spallation source driven by the CERN proton synchrotron.

The project has 6 work packages:

- setting-up of the lead assembly and preparation and instrumentation of the beam line;
- experiments on ARC including timing experiments (CeF_3 counters) and activation experiments (delayed γ counting);
- study of advanced neutronics in lead by electronic experiments, activation measurements and temperature measurements;

- development of an appropriate formalism and computational tools for ARC;
- conceptual design of an incinerating device based on ARC;
- other applications of ARC.

The project has been completed by carrying out the following tasks. The detailed analysis of the data (work packages 2 and 3) has concentrated on the following items: (i) measurement of ^{99}Tc transmutation rate and of the ^{99}Tc neutron capture cross-section as a function of neutron energy with the CeF_3 detector; (ii) measurement of the production rate of ^{233}U from ^{232}Th and ^{239}Pu from ^{238}U using delayed γ spectroscopy; (iii) neutron flux measurements over the lead capture resonance region with ^{3}He chambers working in the ionisation mode; (iv) measurements of the high neutron energy flux (>1.4 MeV) with fission detectors; and (v) thermoluminescence measurements of the neutron flux below 0.5 eV. The computational tools that are indispensable for the interpretation of these data (work package 4) have been developed in parallel. The various detectors have been simulated and the results of simulation have been compared with experimental data in a systematic way. The present assessment of the experimental data confirms clearly the possibility of destroying in an effective fashion ^{99}Tc and ^{129}I by using the ARC method, as well as extending this concept to other applications.

Physical aspects of lead as a neutron producing target for the accelerator transmutation devices

The University of Louvain-la-Neuve is co-ordinating this concerted action, which involves twelve other European research institutions (Univ. Uppsala, Univ. Hannover, PTB Braunschweig, CEA Saclay, CNRS Nantes, Univ. Groningen, NRG Petten, GSI Darmstadt, FZJ Jülich, CNRS Caen, CNRS Orsay, Univ. Liège).

This concerted action started in the second half of 1998 for a two year duration. Its aim is to evaluate lead as a spallation target for the production of high intensity neutrons. The available experimental data are being compiled and compared to predictions from different theoretical models as well as the new measurements, which will be obtained in the EU laboratories in the next two years. The concerted action will be concluded by recommendations on possible additional measurements on lead and on the best codes to evaluate the reaction mechanisms.

The work programme includes the following items:

- Reactions induced by protons (30-70 MeV) and by neutrons (30-65 MeV);
- Production of residual nuclei by protons and by neutrons;
- Elastic scattering of 100 MeV neutrons on lead;
- Fission in proton induced reactions at 190 MeV on lead;
- Spallation induced by protons and deuterons at 0.8, 1.2 and 1.6 GeV;
- Fragmentation of ^{208}Pb ions of 1 GeV.A on hydrogen;
- Particle multiplicities on lead targets induced by protons from 0.8 to 2.5 GeV.

P&T and future systems under the 5th Euratom Framework Programme

The Commission adopted its proposal for the Fifth Framework Programme (1998 to 2002) in April 1997 (content) and in July 1997 (overall budget of 16 300 MECU including 1 467 MECU for Euratom research activities). After a first reading by the Parliament in December 1997, the proposal was amended by the Commission in January 1998. The Council reached unanimous political agreement on a common position concerning the Fifth Framework Programme (FP5) at its meeting on 12 February with an overall budget of 14 000 MECU, of which 1 260 MECU is allocated to the Euratom part of FP5. Because of the difference between the proposal of the Council and that of the Parliament (16 300 MECU as the Commission) for the overall budget of FP5, the conciliation procedure between both institutions started at the end of September to reach a final agreement on an overall budget of 14 960 MECU on 17 November (see Table 1). The adoption of FP5 is expected for December 1998.

Table 1

5th Framework Programme
Agreement between Council and Parliament on 17 November 1998

• Quality of life and management of living resources	2 413	MECU
• User-friendly information society	3 600	MECU
• Competitive and sustainable growth	2 705	MECU
• Environment	1 083	MECU
• Energy	1 042	MECU
• Confirming the international role of Community research	475	MECU
• Innovation and encouragement of participation of SMEs	363	MECU
• Human research potential and socio-economic knowledge	1 280	MECU
• Activities to be carried out by means of direct actions (JRC)	739	MECU
• ***Euratom Framework Programme***	***1 260***	MECU
Total	**14 960**	MECU

The specific programmes implementing the Fifth Framework Programme were proposed by the Commission in May 1998. The Council reached provisional agreements on the content of the specific programmes at its meetings on 22 June and 13 October. The final decision should be taken at the end of 1998. The work programmes are being prepared by the Commission. Targeted calls for proposals should be launched from the beginning of 1999.

There are two specific programmes implementing the Euratom part of FP5 [9]. The first one, named “Nuclear Energy”, has two key actions, one on controlled thermonuclear fusion and one on nuclear fission. In addition, there are generic activities on radiological sciences and support for research infrastructures. The second specific programme is concerning the direct actions to be implemented by the Joint Research Centre. Table 2 shows the breakdown for the budget of the Euratom part of FP5 decided by the Council.

Table 2

EURATOM 5th Framework Programme *Decision by the Council*	
• Key action Thermonuclear fusion	788MECU
• ***Key action Nuclear fission***	***142MECU***
• ***Generic research on Radiological Sciences***	***39 MECU***
• ***Support for infrastructures***	***10 MECU***
• Joint Research Centre	281MECU
Total	**1 260 MECU**

The overall objectives of the key action on nuclear fission are to enhance the safety of Europe's nuclear facilities and to improve the competitiveness of Europe's nuclear industry. The more detailed aims are to ensure the protection of workers and the public from radiation, to assure a safe and effective management and disposal of radioactive waste, to explore more innovative concepts and to contribute to the maintenance of a high level of expertise in nuclear technology.

The key action on nuclear fission comprises four chapters: (i) operational safety of existing installations (ageing effects; severe accidents); (ii) safety of the fuel cycle (waste management and disposal, decommissioning; partitioning and transmutation); (iii) safety and efficiency of future systems and (iv) radiation protection.

In the area of partitioning and transmutation, strategy studies are foreseen to investigate its benefits and compare different methods such as critical and sub-critical systems taking into account the whole fuel cycle. New efficient and selective processes will be developed for the separation of the critical long-lived radionuclides from high level and medium level waste (e.g. hydro-metallurgical processes, chromatography and pyro-chemical processes). Basic nuclear data essential for transmutation and the development of ADS will be measured and computed. The radiation damage induced by spallation reactions in materials will be investigated. It is foreseen to develop and test fuels and targets for actinide and long-lived fission product incineration. The preliminary study of an ADS is also considered in the programme with supporting research work on sub-critical mock-ups, safety, coolants (liquid metal or gas), the confinement of the accelerator/reactor window and high power accelerators. Finally, new specific matrices could be also developed for the conditioning of long-lived radionuclides, which cannot be transmuted.

The future systems foreseen in the programme are innovative or revisited concepts. The objective is to assess new or previously discarded reactor concepts, that would be potentially cheaper, safer, more sustainable, producing less waste and reducing the risk of diversion (e.g. gas-cooled fast neutron reactors, high temperature reactors). Small reactors will be evaluated, identifying those of potential interest to the market beyond the next decade. The commercial potential of special applications of nuclear energy, such as combined heat and electricity production, desalination, hydrogen and methanol production will be investigated. Innovative fuels will be studied with advantages in terms of use of fissile materials, robustness to severe accidents and long-term storage. New fuel cycle concepts will be evaluated and developed (e.g. thorium fuel cycle and integral reactor with on-line reprocessing and fuel fabrication).

Conclusion

Under the 4th Framework Programme, the European Commission only devoted limited funding to research work on partitioning and transmutation. Nevertheless, about 40 European research laboratories are participating to these studies, which cover a wide range of scientific areas from partitioning techniques to transmutation in accelerator-driven systems. Most of the projects will be completed in the spring of 1999. Significant results have already been obtained: for instance, in the fields of partitioning of minor actinides by aqueous processes, strategy studies of P&T involving critical reactors and ADS, assessment of the thorium fuel cycle and transmutation experiments. These results could be used as an input for research projects in the next Framework Programme.

In the key action on nuclear fission of the 5th Framework Programme, a substantial part of the research work should be devoted to partitioning and transmutation and future systems. The 5th Framework Programme should be adopted by the European Union at the end of 1998. It is foreseen to make targeted calls for proposals from the beginning of 1999.

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