FIVE YEAR ASSESSMENT REPORT

RELATED TO THE

SPECIFIC PROGRAMME:

NUCLEAR ENERGY

COVERING THE PERIOD 1995 - 1999

The Panel:

Nuclear Fusion	Nuclear Fission
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Foreword

The specific EURATOM Programme comprises two key action, "Controlled Thermonuclear Fusion" and "Nuclear Fission, generic research on Radiological Sciences and Support for Research Infrastructures". This programme is being implemented through indirect research and training actions as provided for in Annex III to the 5th Framework Programme. The strategic goal of the specific programme is to continue the implementation of the established EURATOM Programme in line with the requirements of the EURATOM Treaty, which aims to help exploit the full potential of nuclear energy, both fusion and fission, in a sustainable manner.

The historical background and activities within the Nuclear Fusion and Nuclear Fission Programmes are very different in nature. The Fusion Programme embraces all the research activities undertaken in the Member States (plus Associated countries) aimed at harnessing fusion, to enable the joint creation of prototype reactors for power production to meet the needs of society. The overall objective has been to establish the scientific and technological base the "next step", meaning the next generation of machines after JET. Whilst the Fission Programme provides support to a diverse range of scientific and technical projects aimed at enhancing the safety of Europe's nuclear installations, improving the competitiveness of Europe's industry, ensuring the protection of workers and the public from radiation and helping to solve waste management and disposal problems.

Due to the very different nature of these key actions, it was decided by the European Commission to constitute separate 5 year Assessment Boards for the Nuclear Fusion and Nuclear Fission areas. These Boards have worked independently and the results of their assessment are presented as two separate self-contained reports. The Executive Summaries of these reports are presented in the following two sections.

Executive Summaries and Recommendations

Specific Programme: Nuclear Energy - Nuclear Fusion

- INTRODUCTION

Future long-term energy scenarios show a steady increase in world-wide energy demand, driven by the increase in the global population and the rapid growth in energy consumption per capita in the developing economies. In parallel, there is an increasing awareness of the environmental impacts of energy such as the climate change impacts arising from the burning of fossil fuels. Consequently, the need for new non-polluting and sustainable forms of energy is growing. The harvest of renewable energy is already partly developed but there are issues associated with its availability, location and integration into the network; nuclear fission is another available option although there are concerns about its safety and the long-term issues of waste disposal. Fusion still requires further research and long-term development but appears to have the potential to provide a CO_2 emission-free, sustainable, safe and clean high-density energy option.

- OBJECTIVES

The long-term objective of the European Fusion Programme is to embrace all the research activities undertaken in the Member States (plus Associated countries) aimed at harnessing fusion, and to enable the joint creation of prototype reactors for power production to meet the needs of society. During the past 5 years, activities to establish the scientific and technological base for the 'Next Step', a machine demonstrating a burning plasma under reactor conditions, have been a major focus of the programme. In the 4^{th} and 5^{th} FPs this has centred on ITER, and Europe has been an active participant in the engineering design activities together with Japan, the Russian Federation and the USA.

- MAJOR ACHIEVEMENTS

The Fusion Programme is probably the best example of European Added Value in the Community's R&D Programme and can be considered as a model for the European Research Area. The good co-ordination and co-operation between the Community and national research programmes has enabled far greater achievements to be made than would be possible at a national level. During the last 5 years, the Programme has produced a wealth of high quality results in line with its objectives. The major European activity at JET and in the ITER Project has brought world visibility and has established Europe in the leading role in fusion activities world-wide.

The JET Programme has met all the objectives defined in the 1978 Council Decision and those of subsequent extensions and has exceeded original expectations; JET remains the most relevant machine for supporting reactor-orientated fusion research world-wide and is currently the only tokamak capable of D-T operation. The work on JET is complemented by the studies on concept improvement, long-term technology and safety and environmental studies, undertaken within the national research institutes in Europe, using a range of fusion machines. Together, these activities have enhanced the level of understanding in fusion science, demonstrated a number of the key features of the technical design for a ‘Next Step’ machine and enabled the development of a detailed and fully integrated design for such a machine.

Major achievements towards the ‘Next Step’ during the period include:

- Successful D-T campaign resulting in the production of record fusion power at JET (>16 MW for about one second, and 4-5 MW for about 4 seconds, generating 22 MJ of fusion energy) and the demonstration of alpha heating, a pre-requisite for the ‘Next Step’.
- Demonstration of ‘Next Step’ relevant technologies such as remote handling complex in-vessel components and closed cycle tritium handling.
- A substantially increased level of involvement by European industry, both in the assessment of ITER design reports and in the construction of components. For example, the fabrication of a large superconducting model coil (scale 1:3) for ITER.

The programme has contributed to the development of a strong and competent scientific, technological and industrial community. During the past 5 years, the programme has directly employed around 2000 scientists and engineers (including about 250 PhD students). It has directly contributed to Community policies on training and has the highest level of mobility of researchers of any European Programme at around 500 person-months per year.

European industry has grown in competence together with the fusion programme and can provide all the manufacturing and technical support required by the programme. The high level of technical sophistication and exacting requirements of the programme in areas such as superconductors, remote handling, vacuum technology, power electronics and brazing and welding, has enhanced the skill base and the quality of standards found in European industry. This has led to substantial developments in their specialised capabilities, personnel enhancement and the quality of their products.

Europe now has by itself all the required technical, engineering and industrial capabilities to proceed to the ‘Next Step’ and take the fusion programme forward.

- LESSONS LEARNED AND CONCLUSIONS

Many lessons have been learned from the Fusion Programme of which the following three are of particular importance:

- Large, long-term R&D projects require strong and constant sponsorship and high profile and competent leadership. In the past, the European Union (and some Member States) have given such sponsorship to the Fusion Programme and, in particular, to JET. This allowed the programme management to exploit the Programme very effectively.

  ITER, in its highly international configuration (which has inevitably introduced complications both at the strategic and management level), seems to have progressively lost sponsorship, despite the excellent work done by the entire ITER team. The US withdrawal from ITER (1998) and the financial crisis in the Russian Federation has led to the requirement to redesign a lower cost New-ITER with less ambitious objectives. Moreover, international uncertainty still exists.

- Such long-term, challenging and costly programmes require a firm, stable and powerful legal framework within which to be managed. Again, the JET experience is meaningful and, with the obvious adaptations to the new context, a legal framework with greater management responsibilities coherent with the requirements of the Next Step will have to be adopted.
- The fusion community has always stressed the differences between fission and fusion in terms of safety and environmental impact, and all the studies done in the recent years confirm this point. Nevertheless, the general public still tends to view the two technologies in the same light. More attention is required on this issue.

During the last 5 years, the programme has achieved very important results, confirming fusion should now be considered as a credible option in the search for clean, large-scale power generation systems. Nevertheless, there are still a number of important scientific, technological and engineering issues to be addressed before a commercial power plant can be realised. At least two more generations of machines are envisaged before building a prototype reactor and, based on present planning, large-scale electricity would be produced in around 50 years. Recent history has shown how sensitive the Programme is to delays in the decisions. The postponement of the construction of ITER has already introduced a delay of almost 10 years.

From the organisational and programme point of view, the last 2 years have been particularly complicated for the Fusion Programme due to the need for new organisational structures and framework agreements and due to the high level of uncertainty regarding the ‘Next Step’. The Board’s impression is that, in spite of this situation, the programme has been well co-ordinated and efficiently run by the Commission as shown by the results obtained.

- RECOMMENDATIONS

1. The European Fusion Programme has helped to place European science, technology and industry at the leading edge of development in this sector and this advantage should be defended and possibly increased.
2. The European Fusion Programme should continue to be reactor orientated and the construction of the 'Next Step' should be started in FP6. This should be the first priority and some of the budget should be specifically earmarked for the Next Step. The budget should be at least at the present level, although a constant budget may lead to a reduction in the funding available for the other activities. If the budget continues to remain at the same level in FP7 and FP8, the Board believes it will still be possible to finance the completion of the construction of the Next Step, provided there is a reorientation of the activities in the national research institutes.
3. To proceed with the ‘Next Step’ in the international collaboration perspective of the New-ITER, the European Union should within the next 2 years:

- Conclude negotiations on the legal and organisational structure of the future venture

- Actively seek a European site for the New-ITER, since this is the best option from a European viewpoint.
- Conduct a thorough review of the financial issues, including the different financial costs and benefits of siting it in Europe, Canada or Japan, and establish the extent to which Japan would support the construction of New-ITER outside Japan.
- Examine in detail the recent interesting expression of interest received from the Canadian Consortium.

4. In the same 2-year period, due to the uncertainty over the outcome of the international negotiations, Europe should study an alternative to New-ITER, which would be suitable to be pursued by Europe alone. For example, a copper magnet machine which would still achieve the required objective of demonstrating a burning plasma under reactor conditions even if this would delay the integration of the superconducting technologies. Europe would then be ready by mid FP6 to drive forward the development of fusion even in the event of a further lack of positive decision on the construction of the New-ITER.
5. In the meantime, in FP5, limited investment on JET should be allowed to exploit the full value of the machine. This will also enable the fusion community to further prepare for the operation of the 'Next Step'.
6. The Fusion Programme, as part of a long-term sustainable energy policy, is highly demanding from a political and operational viewpoint and requires renewed support from the political authorities with an explicit endorsement of the tight timescale suggested for the 'Next Step'.

   In view of the Programme's evolution to a more managerial phase, a more innovative operational solution should be studied, to be approved together with FP6. There are several alternatives, such as an agency in charge of the entire fusion programme (and EFDA could be considered as a first step) or a legal entity belonging to Euratom, to be responsible for the implementation of the Next Step including the management of the money earmarked for this specific objective. In any case, the Committee structure governing the fusion programme should be streamlined.
7. Following a positive decision on the construction of the Next Step, a refocusing of the European Programme will be required. For this purpose, a critical assessment of the different European machines and their funding should be undertaken.
8. A Materials Research Programme is necessary to develop high performance, low activation materials for machines after the 'Next Step'. This programme should be run in parallel with the 'Next Step' to ensure the materials are ready when required and should include new materials concepts. It is recommended that international discussions on a 14 MeV neutron source Materials Testing Facility or alternative testing solutions are brought to a decision on a timescale consistent with reactor development.
9. The public acceptance of fusion is a key factor in its development as an energy option. Concern on this point has been expressed in several of the recent annual monitoring reports for the fusion programme despite increased effort on the safety and environmental aspects of fusion. Environmental issues should be considered as a full programmatic action, using a broader and more structured approach, in parallel to reactor development (Figure 6 in the report). The programme should

continue to address issues such as fuel cycle management, waste management and recycling and all the safety aspects. In the short-term, a small Working Group could be set up to review the safety and environmental results obtained to date and to actively promote the benefits of fusion power to a broad range of political and public stakeholders.

10. There are various examples where there has been the transfer of technologies, skills and experience from the fusion programme to other areas of science and technology, and evidence for the transfer of know-how and experience to European industry. Such transfers should be exploited in a more structured and entrepreneurial way in response to market demand.

Specific Programme: Nuclear Energy - Nuclear Fission and Radiological Sciences

This report covers the 5 years assessment of the research performed in the period 1995-1999 under Nuclear Fission Safety in Framework Programme 3 (FP3) (1990-1994), Framework Programme 4 (FP4) (1994-1998) and Key Action 2: Nuclear Fission and Research of a Generic Nature in Radiological Sciences in Framework Programme 5 (FP5) (1998-2002) under the heading of Research and Training in the Field of Nuclear Energy. It is presented in the format of FP5. The overriding objectives of this field of activity are to enhance the safety of Europe's nuclear installations and improve the competitiveness of European industry. Within these broader objectives, the more specific aims are

- to contribute to the protection of workers and the public from radiation and the safe and effective management and final disposal of radio-active waste,
- to explore innovative concepts that are sustainable and have potential longer term economic, safety, health and environmental benefits,
- to contribute towards maintaining a high level of expertise and competence in nuclear technology and safety and
- to contribute towards the safe and competitive use in other industries and medicine of ionising radiation and towards the safe management of natural sources of radiation.

This area of research has been developed over many years and these objectives are to be seen in the light of continuous progress towards a coherent but evolving body of knowledge. The achievements of the programme during the past five years are many and diverse and are summarised below. Overall we believe that the standard of scientific quality has been maintained at a high level and that much European Added Value has been achieved through joint projects, networking, information dissemination and a general improvement in understanding of common problems. The research has been of value to a number of end users, including Industry, Regulators, Research Institutes and more generally to people involved in the use of or exposure to radiation However, we note that the resources available to this important area of research have been reduced during the evolution of FP3 - 4 - 5 to the point now that some of the basic objectives for operational safety, radiation protection and waste can no longer be achieved. In addition this could threaten the essential continuity of research in an area which depends on long term development.

The processes of management of the programme are improving, but are still heavily bureaucratic and cumbersome. This could be improved by giving more authority to Commission staff to manage once agreement has been reached on the overall objectives and content of the programme. In a similar vein, project co-ordinators need to be able to show more flexibility and leadership once projects have been awarded.

Major Achievements. There have been many significant achievements from the diverse and comprehensive coverage of research topics in this area. These are highlighted below according to the headings of FP5. More detailed descriptions are available in the main text under the same headings.

Operational Safety of Existing Installations.
Plant Life Extension. This area of Research was not identified separately in FP4, but a number of projects of relevance were carried out. These have lead to a much better appreciation of the interacting aspects of materials performance which have to be drawn together to optimise plant life management. Thematic networks have been very successful in this area, leading to, for example, laying the ground work for qualification and industrial validation of methods for the non-destructive examination techniques for aged material. Future work should be focused on the needs of Regulators.
Severe accident management. Research in this area has made an important contribution to an international effort over many years to develop an understanding of severe accident (core melting) phenomenology. Whilst an area as complex and diverse as this is never likely to be "closed", it is clear that a degree of maturity has been achieved and this has lead to the direct use of the research results in developing severe accident management schemes, both preventative and mitigative, and in providing a sound basis for innovative new designs. Specific results in severe accident research that underpin these conclusions include:

- The improved understanding of the coolability of corium ex-vessel.
- The reduction in the estimated likelihood of a major in-vessel steam - explosion.
- The improved understanding of the deflagration of hydrogen leading directly to better methods of control.
- The minimisation of the threat to containment from Direct Containment Heating (DCH).
- A better understanding of the leakage of aerosols through micro-cracks in concrete leading to a reduction in the expected fission product release following a severe accident.
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Safety of the Fuel Cycle. This area covers a very diverse range of issues. Questions of spent fuel management and disposal are often dealt with at a national level, but there are a number of common issues, such as repository performance assessment. The balance of research has shifted from waste management (which are relatively near term issues) to Partitioning and Transmutation (which is increasingly seen as being very long term). This is reflected in our recommendations.

In waste and spent fuel management and disposal a number of projects have been particularly successful. These include:

- Experiments in underground Research facilities have been the focus of international collaboration. Eventhough the EC funds only a small fraction of these major long term projects, it gets good added value through encouraging team work and sharing results.
- The Spent fuel Performance Assessment Project (SPA) covered all elements needed to come to a total system analysis of spent fuel disposal in various host rock

formations. Major achievements were made in the linking of laboratory work, data from field experiments and modelling. This showed clearly where there were still deficiencies in knowledge and challenges for strategy. Progress was also made through the input of natural systems studies.

- Many uncertainties remain that need to be clarified through continued basic studies. Studies on basic phenomena such as natural analogue projects (e.g. the Palmottu and Oklo projects) were very successful; progress was also made in other areas, such as migration and corrosion.

Partitioning and Transmutation. A re-appraisal of the possibility of separating and/or transmuting long-lived radioactive species has lead to a new interest in research in the area. In contrast to some other important areas the EC budget for research in P&T has increased considerably during the past five years. This priority is controversial. Research to date in transmutation strategies has shown that any plan to "burn" plutonium or other minor actinides will require a very long time and will require the investment of very large sums in the technology. It is not clear which technology will prove the most attractive (ADS[1] or LMR[2]) and further strategic studies including safety and waste management are needed before any significant investment decisions are made. Because of the long-term nature of this work, on balance we believe it would be more appropriately placed in the area of Safety and Efficiency of Future Systems. In partitioning there has been specific progress in the separation of trivalent actinides (americium and curium) from lanthanides which could lead to a process with a single cycle allowing direct extraction of the minor actinides from the very high level liquid waste which results from reprocessing.

Safety and Efficiency of Future Systems. This is a new area established for FP5, although related topics were included in FP4 under the heading of Innovative and Revisited Systems. Its aims include assessing new or previously discarded reactor concepts that would be potentially cheaper, safer, more sustainable, producing less waste and reducing the risk of diversion. The development of nearer term evolutionary plant is seen as being the responsibility of national or multi-national programmes. Results from the previous programmes have demonstrated the technology of some passive safety systems.

Radiation Protection. In FP5, this area was introduced as an end user oriented part of the key action 2. It contains a number of sections that overlap to some extent, each of which is covered below. It is intimately related to the following section on Generic Research in Radiological Sciences and we shall recommend that these two sections be considered together in future.

Risk Assessment and Management. Tools for risk assessment and management have been further developed. There has been an appreciation of the need to better understand how acceptance of risk at a social level can be achieved and the project TRUSTNET is an important contribution to that, and is continuing in FP5. The ETHOS-project was particularly successful in showing how the involvement of the local populations is vital in the rehabilitation process.

Monitoring and Assessment of Occupational Exposure. Progress in optimisation of occupational
exposure in a variety of applications resulted in recommendations to the EC, national authorities

[1] ADS; Accelerator Driven Systems
[2] LMR; Liquid Metal Reactors

and utilities on the use of the ALARA-principle.

Off-site Emergency Management. The RODOS system for assisting in off-site emergency management is now available for operational use. It represents the work of 40 Institutes in 20 different countries (in both the East and the West).

Restoration and long-term management of contaminated environments. Models have been developed to identify areas with high transfer capacity of caesium. Significant progress was made in the development of more holistic countermeasure strategies by integrating issues of private and environmental costs and benefits, environmental management and consumer attitudes and behaviour into the countermeasure selection process.

Generic Research in Radiological Sciences. Estimates of the risks from exposure to ionising radiation are the basis of all radiation protection, thus they have to cover the wide range of radiation types and exposure conditions in the natural environment, the work place and the clinic to be of practical value. The following are some of the important achievements in this area.

Radiation protection and health. Co-ordination of work under FP3 and FP4 in this field has lead to a deeper understanding of the mechanisms by which radiation exposure leads to the induction of cancers and particularly on predisposition. Recent developments in gene research, molecular biology, irradiation techniques (single cell irradiation using soft energy microbeams) and computer modelling provided new possibilities to improve our knowledge of the effects of low doses of radiation.

Environmental transfer of radioactive material. The work has focussed on a better understanding of transfer mechanisms and developing of ecological models to predict the fluxes of radionuclides in different types of environment. For the future, a holistic approach to environmental protection including radiation protection is required.

Industrial and medical uses and natural sources of radiation. Progress has been made in the field of optimisation in intervention radiology (IR), paediatrics, Computer Assisted Tomography (CT) and fluoroscopy as well as developing image quality criteria. Because of the higher sensitivity of children to radiation a number of studies have focussed on developing guidance on paediatric radiology. For natural sources of radiation, studies on the risk arising from the inhalation of radon and its decay products, including lung modelling, epidemiology, and an intercomparison of passive radiation detectors, produced important results.

Internal and external dosimetry. Biokinetic and dosimetric models have been produced to improve estimates of dose from intakes of radionuclides by adults and children. An extensive database of dose coefficients was published to meet the needs of health physics practitioners and researchers in radiological protection. A real breakthrough was achieved in mixed neutron detection with important commercial possibilities.

Major Conclusions and key issues for the future.

Overall recommendations and conclusions are given in section 7 of the main report. Recommendations concerning specific issues are included in the appropriate sections of the main text. The following is an abbreviated summary of the main conclusions and issues for the future.

1. The five years assessment has shown that the specific programme in nuclear fission safety continues to provide results of high scientific value, which are relevant to the needs of Industry, Regulators and those concerned with radioactivity generally. It is seen as meeting most of its overall objectives.
2. The reductions in funding of FP3, FP4 and FP5 mean that sufficient funds are not available for important research needed to tackle key objectives of the programme.
3. The Commission staff should be empowered to be more pro-active in seeking research needed to fulfil agreed programme objectives.
4. Project co-ordinators should be given more freedom to manage the work, including financial flexibility once clearly defined responsibilities have been established and projects awarded.
5. The title "Nuclear Fission" no longer represents the current balance of the programme. We suggest that Radiation Protection be grouped with Generic Research in Radiological Sciences separately from Nuclear Fission.
6. The time frame for developing the technology for Partitioning and Transmutation is very long. We therefore believe that it should be considered in future along with "Safety and Efficiency of Future Systems" so that its funding and priority can be better judged as it is linked directly to the long-term needs of the Community.
7. European Centres of Excellence are supported in principle, but care is needed to guarantee the input of creative research activities and not to create monopolies.
8. Networking has proved to be a useful tool and should be further developed and given a higher priority in future.
9. A vision and strategy needs to be found in order to rationalise the training aspects of the programme as they make a potentially important contribution to the maintenance of the knowledge and skill base in the future.
10. Common strategic planning should be reinforced between FP and JRC programmes, and more co-ordination directed towards the needs of other concerned DGs, in particular to support horizontal actions.
11. Scientific dissemination is generally very good. Dissemination of research results is important for non-specialist end users, decision-makers and the public and should be done professionally.
12. Efforts should be made to make research data and tools available to other parts of the FP and to a wider technical catchment area. For example ESA where radiation effects are of importance.
13. A common theme emerging from many of the research areas is risk governance. Developing an understanding of such complex systems is not limited to nuclear activities and we recommend that very broad inter and multi disciplinary studies are undertaken by the Commission as a horizontal activity.

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FIVE-YEAR ASSESSMENT OF THE SPECIFIC PROGRAMME: NUCLEAR ENERGY:
Nuclear Fusion

FINAL REPORT

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May 2000

1 Board Members

Board Member	Occupational and Professional Experience
Prof A Airaghi (Chairman)	Senior Vice President Finmeccanica. Chairman and member of the Board of various companies. Vice Chairman of the Italian Federation of Electromechanical, Electronics, Telecom and Informatics Industries (ANIE).
Prof H Condé	Professor Emeritus of Applied Neutron Physics at Uppsala University and former Senior Scientist in Neutron Physics at the National Defence Research Establishment. Former member of the Nuclear Data Committees of IAEA and OECD.
Prof C Matos Ferreira	Professor of Physics and co-Director of Centre for Plasma Physics at Instituto Superior Tecnico (IST), Lisbon Technical University. Presently, Chairman of the Scientific Council of IST and member of the COST Technical Committee for Physics. Former member of the Executive Committee and the Council of the EPS. Extensive experience in low-temperature plasma physics, plasma kinetics, and atomic and molecular physics of ionised gases.
Dr Ing G Newi	30 years experience in power engineering and utility management. Presently, Managing Director of CONSULECTRA, a consultancy subsidiary of Hamburgische Electricitats-Werke AG. Member of Fachbeirat for IPP Garching.
Dr P H Rebut	Member of the French Académie des Sciences. Advisor to the “Haut Commissaire à L’Energie Atomique” (France). Former Director of JET and ITER.
Prof A M Stoneham	Presently, Massey Professor of Physics and Director, Centre for Materials Research at University College London. Fellow of the Royal Society. Fellowships of the American Physical Society, Institute of Physics and Institute of Materials. Previously, Chief Scientist AEA Technology.
Dr J E Berry (Rapporteur)	20 years experience in energy and environmental work. Presently, a Department Manager at AEA Technology, based in Brussels.

2 Introduction

2.1 Fusion has long been recognised as a potential energy source for mankind. Against the current background of increasing world-wide demand for energy, finite resources of fossil fuels and international concerns over climate change issues, nuclear fusion is one of the few long-term energy supply options currently under investigation.

2.2 The long-term objective of the European Fusion Programme is to embrace all the research activities undertaken in the Member States (plus Associated countries) aimed at harnessing fusion, and to enable the joint creation of prototype reactors for power production to meet the needs of society. The Programme has developed to its present standing over the past four decades, starting with the original Euratom Treaty in 1957 and the first Association agreement with CEA, signed in 1959. Since that time the number of Associations has increased to 20, and most recently has extended to include agreements with CEE. Financed wholly by public funds from the Commission and Member State Governments, it represents itself as a single entity in its relations with other international fusion programmes. Collaboration with other non-EU nations (USA, Japan and Russia) plays a key part in the implementation of the Programme. At a European level, the overall expenditure for fusion orientated research has reached 10 billion Euros (1999 value) of which approximately 40% has been funded from the Community budget.

2.3 The specific objectives of the thermonuclear fusion programme have remained very consistent between the 3rd, 4th and 5th Framework Programmes (see Table 1). The overall objective has been to establish the scientific and technological base for the 'Next Step', meaning the next generation of machines after JET. In the 4th Framework Programme this 'Next Step' has centred on ITER. Overall, this has resulted in a scientifically and politically coherent programme.

Table 1: Objectives of the Framework Programmes

Programme	Programme Objectives
3rd FP (1990-94)	"The establishment of the scientific and technological base for the construction of an installation designed to achieve and study the ignition and prolonged combustion of plasma and related technological problems (Next Step)."
4th FP (1994-98)	"The objective of the Next Step activities will be to establish the engineering design of an experimental reactor, in the frame of the quadripartite international agreement ITER, between Euratom, Japan, the Russian Federation and the United States of America."
5th FP (1998-2002)	"To develop further the necessary basis for the possible construction of an experimental reactor. This key action should thus enhance the Community's preparedness, from a scientific, technical, financial and organisational point of view, to decide on and support such a future experimental reactor."

2.4 The European Nuclear Fusion Programme has been organised as a joint effort between the EURATOM and the Member States. This coordination of activities has been successfully achieved by a combination of bilateral contracts between the Commission and the relevant national research institutes (Association Contracts) in each EU Member State and Switzerland, and a series of joint European agreements which have enabled the programme to undertake activities which would have been impossible at a national level. The first major European research initiative was the construction and operation of the Joint European Torus (JET), which has been acknowledged worldwide as a major success and has reinforced Europe's position at the forefront of fusion development. This was established in 1978, as a Joint Undertaking (a solution foreseen in the Euratom Treaty to combine Community and Member States funds) and up until the end of 1999 has been managed by the JET Council, comprising representatives of the Commission and the organisations from Member States. Similarly, the NET Agreement (1983-1998) provided the framework for European collaboration in research and development in support of the Next European Torus and then in 1992 facilitated European participation in the International Thermonuclear Experimental Reactor (ITER) Project which was initially based on a quadripartite Agreement between the European Atomic Energy Community, and the Governments of Japan, Russian Federation and the USA. At the beginning of 1999, the new European Fusion Development Agreement (EFDA) came into force; it has been signed by the Commission and all the national research institutes and provides a framework for the continuity of European activities in the field of thermonuclear fusion. In particular, the EFDA Workplan now includes the technology work carried out by the national research institutes and by European industry, European contributions to international collaboration such as ITER and the exploitation of the JET facilities after 1999. The latter is specifically covered by the JET Implementing Agreement (JIA), between Euratom and the other parties of EFDA, and includes provisions relating both to the technical programme and the financing of the activities.

2.5 During the past 8 years, ITER has been a major focus of European activities. In July 1998, the ITER Engineering Design Activities were completed in line with the initial objectives. It was decided that the design phase should be extended for a further three years to enable the completion of technical tests, the exploration of a less expensive option with less ambitious objectives and the investigation of non-technical issues such as the licensing requirements. In July 1999, the US formally decided to leave the ITER Agreement. This decision has affected the world-wide fusion scenario and requires a new appraisal of the European Programme.

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2.6 The extensive European activities undertaken during the review period, both in direct support of ITER and in the development of concept improvements and longer term technology, have been reviewed against the background of international activities. The Board's activity and this report have been prepared in line with the Broad Guidelines for the 5 Year Assessment of the RTD Framework Programmes issued by the Commission. It has been undertaken in accordance with the legislative requirements as given in Article 5 of the Council Decision of

22 December 1998 on the Fifth EC Framework Programme and the Euratom Framework Programme, and with Article 4 of the Council Decision of 25 January 1999 adopting the Specific Programme in the field of nuclear energy (Euratom).

2.7 The Commission asked a Board of seven independent, external experts to review the implementation of the Fusion Programme over the period 1995-1999. The Board met 9 times in the period 28 September 1999 to 30 April. In order to review thoroughly the activities of the programme, the Board members undertook an extensive series of visits, meeting representatives from 16 national research institutes. This enabled them to discuss directly with the institutes' staff the activities being undertaken and their role within the European Fusion Programme. (Details of the activities at each of the national institutes are included in Annex 1). In addition, the Board has been provided with a large number of papers describing different aspects of programme.

3 Assessment of Implementation and Achievements

3.1 EFFICIENCY

3.1.1 Fusion is a highly challenging, long-term, scientific and technological objective. Its development requires permanent relationships and clear and stable mission definitions. The Fusion Programme provides a framework for a decentralised structure comprising a series of bilateral Association Contracts (between the Commission and national research institutes) and a number of specific fusion programme agreements (see Annex 2). The programme management in Brussels accounts for less than 1.5% of the community budget. This structure has provided a framework for the technical co-ordination and financing of European activities that is well accepted by the scientific, technical and industrial players in this field. It explicitly gives them responsibilities relating to the management, technical and financial direction of their work and, up to now, has proved to be satisfactory. This structure will need to be reviewed in light of the future development of the programme.

3.1.2 In the 4^{th} FP, the European Fusion Programme was a separate programme but in the 5^{th} FP, the Fusion Programme is a Key Action within the Preserving the Ecosystem Programme; this has increased the overall complexity of the management structure. In the 4^{th} FP, the Fusion Programme was co-ordinated by the European Commission, advised by the Consultative Committee for the Fusion Programme (CCFP) and the STC Euratom. In the 5^{th} FP, there is also an advisory body for the Key Action and in practice there is some overlap between the responsibilities of these groups.

3.1.3 The JET Joint Undertaking was a novel solution to combine EC and Member State funds. This solution proved to be a good framework with the exception of the statute concerning staffing. Staff were seconded to JET through two employers, namely the UKAEA and the Commission, which led to tensions and legal problems, and contributed to the termination of the Joint Undertaking with the loss of experience and some competent staff. It is hoped that the new European Fusion Development Agreement will continue to provide the required flexibility, at least in the short-term. The staffing issues have been specifically addressed, although the staff seconded under the new arrangements will take some time to become as effective as the previous staff.

3.1.4 Fusion, as a long-term programme, requires the highest level of continuity. Late adoption of the Council Decisions concerning the extension of JET and the successive FPs has made the continuity of the programme and investment difficult. The change in the legal framework from the Joint Undertaking to the new EFDA framework is creating difficulties for the operation of JET during the present transitional period. It is envisaged that the new arrangements under EFDA will enable the further exploitation and subsequent closure of JET; presently, there is only a legal framework for fusion activities up to the end of the FP5.

3.1.5 The Fusion Programme has been affected by the unavoidable break in the flow of funds between successive Framework Programmes. However, within the national research institutes, the "association contract formula" has ensured continuity between successive Framework Programmes. As a consequence, from the technical viewpoint, the transition between the FPs has been relatively smooth, and has enabled the programme of work to proceed without any major interruptions.

3.1.6 Due to the specialised nature of the Programme there has been only limited co-ordination with other Programmes under the FPs. The only exception has been the need for co-ordination with the fusion related work undertaken within the JRCs. This need has declined following the decision of the JRCs to withdraw from fusion work. At present there are a few 4^{th} FP projects nearing completion but no new activities under 5^{th} FP.

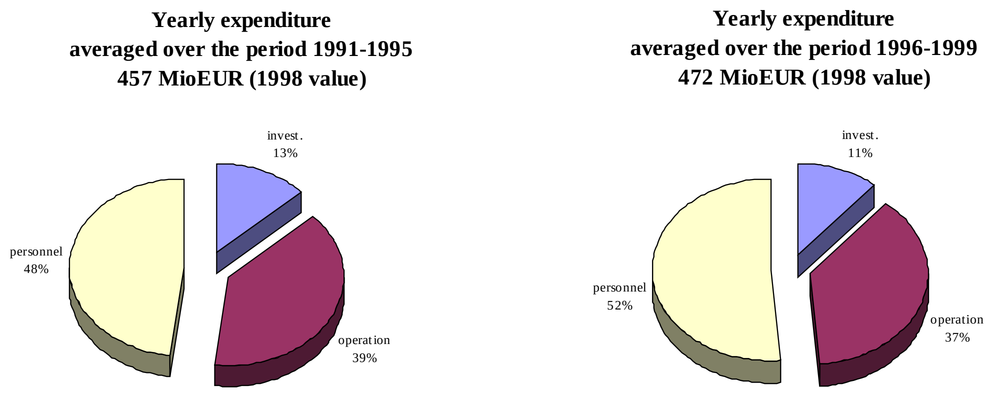
3.1.7 Potential opportunities for the cross-benefit of the Fusion Programme with other framework programmes, for example in the areas of materials and remote handling, have not been fully exploited.

3.2 EFFECTIVENESS

3.2.1 The stated scientific and technical objectives of the Fusion Programme have been achieved and almost always met within budget. The total yearly expenditure on Fusion R&D, averaged over the period 1996-1999, has been around 3% higher than that in the previous 5 year period (Figure 1). Whilst the total level of investment has remained approximately the same, there has been a major shift in the nature of the investments. During the period 1991-1995, 34% of the investment was on JET whereas, during the last 5 years, this has dropped to under

4% with substantial increases in ITER related activities and within the National research institutes. The 4% increase in personnel costs reflects, in part, the 'ageing' of the staff involved in the Fusion Programme.

Figure 1



3.2.2 The Community contribution to the overall budget has decreased from 44.6% (period 1991-1995) to 41.5% (period 1996-1999) as shown in Figure 2. There has also been a shift in the distribution of Community funding between the different areas of the programme (Next Step, JET, Concept Improvements, Technology and Administration). The level of funding for Next Step activities has increased, balanced by a decrease for Concept Improvements and Technology. This is in line with the increased emphasis on the Next Step activities during the past 5 years.

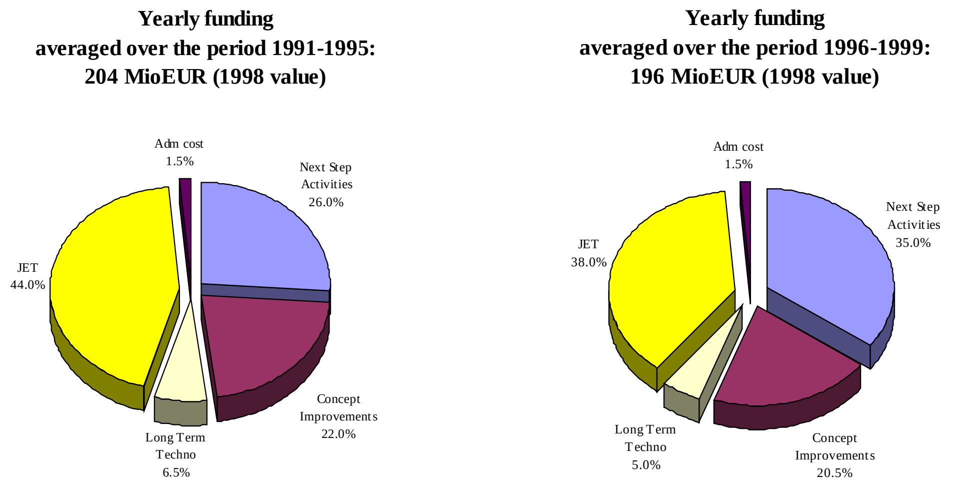


Figure 2

3.2.3 The European Fusion Programme has produced a wealth of high quality results in line with the objectives of the Programme (see Section 5.3). The major European activity at JET and in the ITER Projects has also brought world visibility, which in turn helps to promote high class European research capabilities and has established Europe in a leading role in fusion activities world-wide.

3.2.4 The Programme has been developing the technologies and improving the concepts required to develop nuclear fusion as a future energy source. It has concentrated effort on the use of magnetic confinement and mostly on tokamaks. The success of JET operations tends to support this decision.

3.2.5 To date, the JET Programme has met all the objectives defined in the 1978 Council Decision and those of subsequent extensions and has exceeded original expectations. The successful JET Deuterium-Tritium campaign, the development of an active gas handling system and the sophisticated remote handling facilities demonstrate the direct applicability of the science and technology activities to the overall objective of developing fusion as a long-term energy source.

3.2.6 The ITER machine has been conceived as an important step towards the development of a prototype fusion reactor. One of its defined objectives is to demonstrate ignition. The combined effect of the US withdrawal from ITER in July 1999, the economic problems in Russia, the moratorium on large-scale research investment in Japan, and the unwillingness within Europe to invest more money in the construction of ITER, necessitated a reappraisal of the ITER objectives, design criteria and the cost of the machine. The subsequent decision to extend the design activities until 2001 and proceed with the design of a new machine (New-ITER), with a less ambitious set of scientific objectives[3] and approximately 50% reduction in budget, has required additional design work. This work has been able to draw on the same scientific basis on which the original ITER design was based and a viable alternative has been designed. The relatively short timescale on which this has been achieved has demonstrated the overall efficiency and effectiveness of the ITER teams.

3.2.7 The delays in the decision process regarding the construction of ITER, and the entry of the programme into a new generation of machines, has encouraged the continued exploitation, and in some cases further development, of existing machines. This approach has helped to control the loss of highly qualified researchers and contributed to enriching the knowledge and databases. A reappraisal of the existing machines is recommended for the future.

3.2.8 The Thermonuclear Fusion Programme is probably the best example of European Added Value within the FPs. The only other research activity within Europe on a similar scale is CERN. The nature and range of activities/expertise and the large capital investments required in the fusion area would limit the level of activity that could be undertaken within the national budgets in any individual Member State Association. Good co-ordination and co-operation between the Associations (16 in 1996, but presently 20) has enabled far greater achievements to be made and, as mentioned above, has enabled Europe to be recognised internationally as leading research in this field.

[3] Originally known as ITER-RO/RC, but referred to throughout this document as New ITER since the ITER Council has still to decide on a name. Designed to achieve a Q gain of 10 rather than ignition and 30% of the original power production.

3.2.9 The Programme requires a highly multidisciplinary research effort drawing on a wide range of different disciplines and skills, (e.g. plasma physics, engineering, mathematics, computing, material science..). The success of the major experiments and the programme over the past 5 years has been largely due to the co-operation achieved within the multidisciplinary, multinational teams responsible for the work. Likewise, the ITER design has benefited from the transfer of experience from the European Programme.

3.2.10 European industry has grown in competence together with the fusion programme and can provide all the manufacturing and technical support required by the programme. The high level of technical sophistication and exacting requirements of the programme in areas such as, superconductors, remote handling, vacuum technology, power electronics and brazing and welding, has enhanced the skill base found in European industry and the quality of standards in industry. In addition, there are a number of examples where industry-based technicians, working in support of the programme, have benefited from the specialist training they have received. Eureka and COST type activities are not appropriate at this stage.

3.2.11 The long-term research and development nature of this Programme has meant that there have been no significant opportunities to contribute directly to other Community policies. Nevertheless, the orientation of the European Programme (see Section 4) towards fusion power production could offer a long-term, clean and safe alternative for the future large-scale production of electricity world-wide and could contribute to the reduction of carbon dioxide emissions. There is reasonable hope that in-depth studies undertaken on the safety of fusion technology during the past 5 years will lead to a wider acceptance of this energy option. Hence, it offers the opportunity for major impacts on future European energy, environmental and urban policies.

3.2.12 In the short-term the programme has provided substantial social benefits. It has contributed to the development of a strong and competent scientific, technological and industrial community. During the past 5 years, the programme has directly employed around 2000 scientists and engineers (including about 250 PhD students). It has directly contributed to Community policies on training and has the highest level of mobility of researchers of any European Programme at around 500 person-months per year. At any one time, around 40-45 young researchers are in receipt of grants for training. In addition, the programme has indirectly supported a considerable number of staff in related support and supply industries. In many cases this has led to substantial developments in their specialised capabilities, personnel enhancement and the quality of their products.

3.3 MAJOR ACHIEVEMENTS DURING THE PAST 5 YEARS

3.3.1 The Next Step activities have been a major focus of the programme, with Europe being an active participant in the engineering design activities for ITER together with the USA, Japan and Russia. The European contribution to ITER has been provided through:

- the European Home Team

- participation in the Joint Central Team.

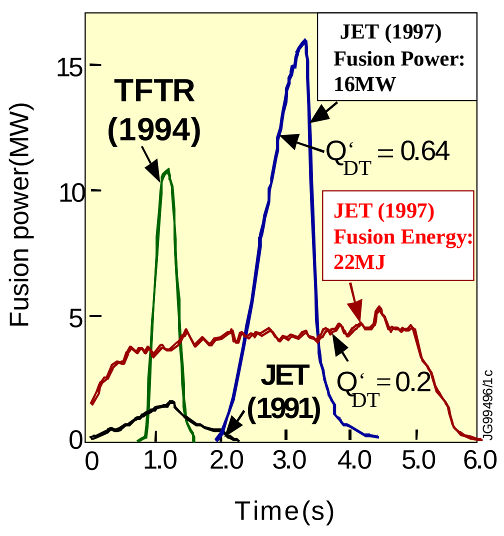
In addition, the majority of the work undertaken at JET during the past 5 years has been in support of ITER, together with a large proportion of the activities within the national research institutes.

3.3.2 Major achievements towards the 'Next Step' during the period include:

- Production of record fusion power at JET (>16 MW for about one second, and 4-5 MW for about 4 seconds, generating 22 MJ of fusion energy – see Figure 3) and the demonstration of alpha heating, a pre-requisite for the 'Next Step'.
- Demonstration of 'Next Step' relevant technologies such as remote handling complex in-vessel components and closed cycle tritium handling.
- A substantially increased level of involvement by European industry, both in the assessment of ITER design reports and in the construction of components. For example, the fabrication of a large niobium-tin superconducting model coil (scale 1:3) for ITER.

3.3.3 JET remains the most relevant machine for supporting reactor-orientated fusion research world-wide and is currently the only tokamak capable of D-T operation. The work on JET is complemented by the studies on concept improvement, long-term technology and safety and environment undertaken using the range of European fusion machines (Table 2), as discussed below. Together these activities have enhanced the level of understanding in fusion science, demonstrated a number of the key features of the technical design for a 'Next Step' machine (Figures 4 and 5 and Box 1) and enabled the development of a detailed and fully integrated design for the 'Next Step' machine. The achievements of the European programme are well recognised world-wide.

Figure 3: Fusion Power Production in JET



Fusion power production in JET (in year 1991 and 1997) and in TFTR (in 1994)

The time traces of several experiments are superimposed for comparisons.

The 1991 experiments in JET were the first ever using tritium, but at 10 % concentration.

The other experiments were performed at near optimum tritium concentration (50 %). The 1997 JET experiments resulted in record values of fusion power and, during a quasi steady-state pulse of 4 seconds, of fusion energy.

Q_{DT}, the fusion power gain, is the ratio between the output fusion power and the additional power injected into the fuel to sustain its temperature.

Table 2: Specialised Fusion Machines in Europe

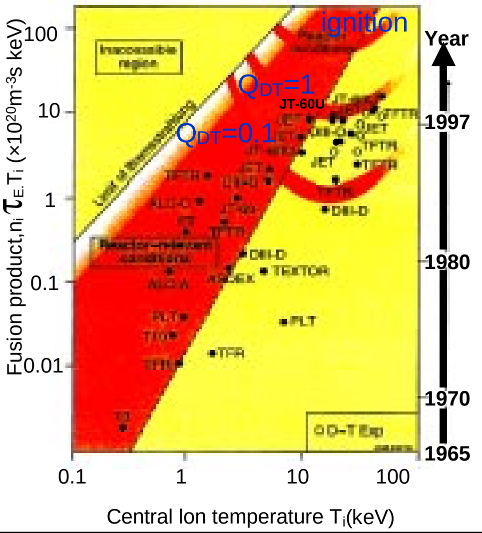
Machine	Association EURATOM	Main objective	Ip [1] (MA)	Start of Operation
Tokamaks				
TORE SUPRA	CEA (Cadarache)	Long-pulse operation in Next Step relevant conditions	1.7	1988 -
ASDEX Upgrade	IPP (Garching)	Poloidal divertor, plasma purity control in ITER and reactor relevant topology	1.6	1991 -
FTU	ENEA (Frascati)	Confinement at high density and high field; current drive	1.6	1990 -
TCV	Switzerland, CRPP (Lausanne)	Physics of strongly shaped plasmas	1.2	1992 -
TEXTOR-94	FZJ (Jülich)	Plasma/wall interaction, edge plasma, confinement with additional heating	0.8	1981 (94) [2]
COMPASS-D	UKAEA (Culham)	High-beta and MHD stability studies in JET / ITER geometry	0.4	1989 (92) [2]
MAST	UKAEA (Culham)	Spherical Tokamak physics at parameters comparable to medium sized conventional Tokamaks	1	1999
CASTOR	IPP-CR (Prague)	Lower Hybrid Current Drive, fluctuations, diagnostic development, edge plasma polarisation	0.025	1977
ISTTOK	IST (Lisbon)	MHD activity, transport, diagnostic development	0.01	1992-
Reversed Field Pinches				
RFX	ENEA (Padova)	RFP physics, toroidal confinement and transport, performance prospects	2.0	1991 -
EXTRAP-T2	NFR (Stockholm)	Stabilisation, shell studies fluctuations, scenarios	0.3	1993 (99) [2]
Stellarators				
Wendelstein 7-AS	IPP (Garching)	Medium-size machine with modular coil system to investigate plasma behaviour in an optimised magnetic field configuration		1990 -
TJ-II	CIEMAT (Madrid)	Highly flexible medium-size machine with helical magnetic axis, e.g. confinement and high-beta studies		1996 -
Wendelstein 7-X	IPP (Greifswald)	Exploration of Stellarator operation at reactor-relevant collisionality towards steady state operation		1997 [3]

(1) Ip Plasma current
(2) Major refurbishment completed
(3) Start of construction 1997, expected to start operation in 2006

3.3.4 Following the recommendations from the previous panel, major effort has been dedicated to the assessment of the safety and environmental aspects of fusion, both in the short and long-term. The 1995 report on the Safety and Environmental Assessment of Fusion Power has been updated, confirming the intrinsic safety-environment advantages of fusion power. In addition, the EU made a significant contribution to the non site specific safety report for ITER which was well received by the ITER Council. Two major conclusions of these activities are:

- Most severe accidents would not require any public evacuation assuming appropriate design provisions are made.
- Almost all the activated material from the reactor could be cleaned or recycled (based on the use of presently available low activation martensitic steel or future advanced materials).

Figure 4: Fusion Performance of Several Machines

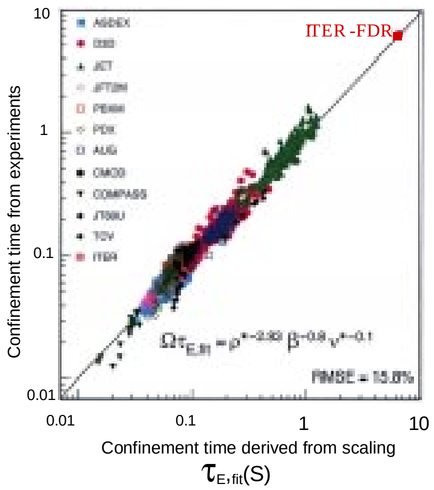


Fusion performance of several fusion devices showing the progress towards the Reactor conditions over the last decades.

JET is the device closest to reactor conditions.

The triple product fuel density x fuel temperature x energy confinement time is a measure of the self-sustaining of the fuel temperature by the deuterium-tritium fusion reactions.

Figure 5: Projection of ITER Performance



Projection of ITER performance

The experimental data from various tokamaks are used to establish scaling laws, from which it is possible to extrapolate to reactor conditions.

The figure shows how such a scaling law on energy confinement time (a measure of the thermal insulation of the plasma) fits the experimental data and extrapolates to ITER. JET provides the data closest to reactor conditions.

Box 1: Major Achievements in Next Step Activities

Next Step Activities in Physics

- There is improved confidence in extrapolations to ITER from semi-empirical studies, in which dimensionless plasma quantities are kept identical (JET; ASDEX Upgrade, IPP; COMPASS, UKAEA), plus experiments showing clear evidence of alpha particle heating in JET D-T plasmas and a 25% lower additional heating power requirement to access the high confinement regime than in pure deuterium. This supports the design variants of the New-ITER developed by the ITER-JCT and the EFDA-CSU aimed at the lowest possible capital cost for a superconducting, ITER-class machine.
- Quasi-stationary high confinement modes with a large radiated power fraction and good power and particle exhaust have been achieved. High density divertor operation and baffling the divertor have been shown to reduce neutral particle flux back into the main plasma chamber, with a clear improvement of D and He pumping (ASDEX Upgrade, IPP).
- Operation in the high confinement "optimised shear" regime has been demonstrated (JET; ASDEX Upgrade, IPP; Tore Supra, CEA; FTU, ENEA), and the associated internal transport barrier sustained in long-pulse operation by plasma current profile control (Tore Supra, CEA).
- A new operational mode for optimising plasma boundary characteristics with respect to radiation level and heat transfer, the "Radiative Improved" or RI-mode has been developed (TEXTOR-94, Etat Belge – ERM/KMS & TEC; ASDEX Upgrade, IPP; JET), and previously established density limits have been exceeded by high field side pellet injection (ASDEX Upgrade, IPP).
- Theoretical models and codes have been developed for the study of: accessible operational space and regimes of Tokamaks (Conf. Suisse), control techniques for mitigating disruptions (UKAEA), improved ICRH and LHCD power coupling (TEKES), MHD effects (RISØ).

Next Step Activities in Plasma Engineering and Technology

- Further development of gyrotrons as sources for ECRH has resulted in world record operation of a 118 GHz tube for >10 seconds at 400kW power output (European industry with CEA, Conf. Suisse and FZK). RF ion sources have been developed for positive and negative ion NBI (IPP; CEA; DCU), and improved launcher design has eliminated arcing on LHCD antennas by (CEA; ENEA; TEKES; Czech Rep.).
- In order to operate Tokamak machines on prescribed trajectories in parameter space for optimised performance, hardware and real-time algorithms for feed-back control using online diagnostic signals have been developed (several National research institutes).
- Better determination of plasma parameters has been achieved by the development of a number of new diagnostics, such as high-resolution Thomson scattering (FOM), a laser fluctuation correlation diagnostic (RISØ), microwave scattering, neutron diagnostics (NFR; ENEA-CNR), reflectometers (IST), heavy ion beam system (IST), Li-beam edge plasma diagnostic (ÖAW; IPP), polarimetry (DCU), and a fast sweeping Langmuir probe (Hellenic Rep.).
- Superconducting strand and jacketing have been manufactured for the ITER toroidal field model coils and the coil has been fabricated (industry). Full size superconducting cables have been tested in the SULTAN facility (CRPP).
- Mock-ups (up to full size) of the first wall, blanket and divertor targets of ITER have been manufactured (industry), and divertor targets have been tested to heat flux levels in excess of the ITER requirement (FZJ; industry).
- Full scale ITER divertor remote replacement/refurbishment facilities have been built and tested (ENEA with participation of Canadian and the Japanese Home Team), and an ITER first wall/blanket remote replacement facility has been built and tested (ENEA). An in-vessel viewing system has been designed and constructed (ENEA; VVT).
- A tritium plant test facility has been realised (FZK supported by ITER Canada) and a torus exhaust cryopump test facility has been realised (FZK).
- A major contribution has been made to the ITER safety assessment.

3.3.5 Research on alternative concepts and new plasma configurations and regimes is an important component of the European Fusion Programme. New tokamak regimes have been studied on several different machines in the national research institutes (Table 2). The results of this work tend to complement those obtained using JET; they explore alternative configurations and broaden the parameter ranges. In addition, they have facilitated the professional training of staff in this field. Developments on these machines have led to improvements on JET, and to the design of the 'Next Step' machine (Figure 4). Major achievements using the tokamak machines during the past 5 years are summarised in Box 2.

3.3.6 Research on alternative configurations is also undertaken by the national research institutes using a range of machines, such as Stellarators and Reversed Field Pinch machines (Table 2). Special mention should be made to the Wendelstein 7-X Stellarator, which is under construction and expected to come into operation in 2006. This represents the largest investment presently being undertaken in the European Programme. Although this machine does not fit exactly with the 'Next Step' tokamak objectives, the decision to determine the potential of the stellarator was taken based on a number of criteria and was recommended in the previous 5 year assessment report.

Box 2: Achievements in Concept Improvements and Alternative Configurations

Concept Improvements on Tokamaks

- Possible improvements in the Tokamak line have been demonstrated by the stability of highly elongated plasmas (k ~ 2.5) near operating limits (TCV, Conf. Suisse), and the achievement of record average beta values of 40% in a Spherical Tokamak configuration (START, UKAEA), followed by the completion of the construction of the Meg-Amp Spherical Tokamak MAST (UKAEA). Repetitive breakdown by current reversal has been demonstrated (ISTTOK, IST).
- The experimental stabilisation of neo-classical tearing modes using ECCD and LHCD (ASDEX Upgrade, IPP; COMPASS-D, UKAEA) has been accompanied by the development of fundamental physics models of stability and transport phenomena (including so-called "first principle" models) into a valuable tool for understanding underlying physics (NFR).

Alternative Configurations

- The exploration of the Stellarator line has continued with the demonstration that the "island divertor" configuration in Stellarators can give access to regimes similar to the those in divertor Tokamaks (Wendelstein 7-AS, IPP) and the successful start of operation of the Heliac Stellarator TJ-II (CIEMAT).
- The superconducting toroidal field demonstration coil for Wendelstein 7-X has been successfully tested (TOSKA, FZK).
- Improvements have been made in the understanding and control of internal relaxation mechanisms in toroidal plasmas using the reversed field pinch (RFX, ENEA-CNR), while the reversed field pinch EXTRAP-T2 (NFR) has been re-constructed to assess different regimes of shell stabilisation, after completion of its first programme phase.
- The Free Electron Maser has been tested at high power (750 kW) in short pulses (FOM).

3.3.7 Specific work on long-term technology has been undertaken by the ITER European Home Team, in the National research institutes, at the JRC and in industry. The effort has been focused on 3 main areas:

- European Blanket Project which aims at designing and constructing relevant tritium breeding blanket modules for testing in ITER
- Assessment of advanced materials
- Socio-economic studies.

Major achievements during the past 5 years are summarised in Box 3.

Box 3: Achievements in Long-term Studies

- The European Blanket Project has been started. Two concepts are being investigated, and progress has been made on the critical technologies of fabrication and materials testing (CEA, FZK, ENEA, FOM-NRG, SCK-CEN).
- A programme of characterisation and testing of low activation ferritic-martensic steels is in progress, and fabrication by European industry of a reduced activation ferritic-martensic steel (EUROFER 97) has been achieved (FZK, CEA, CRPP, ENEA, TEKES, CIEMAT, NFR, FZJ, FOM-NRG, IST, RISØ). Advanced materials are being explored (ENEA, CEA, ÖAW, CRPP, Hellenic Rep., JRC, FOM-NRG, IST), while neutronics and nuclear databases are being further developed (FZK, CIEMAT, CEA, ENEA, ÖAW, UKAEA).
- Studies of the socio-economic aspects of fusion power have started (CEA, IPP, CIEMAT, NFR, ENEA, FOM-NRG, FZK, FZJ, ÖAW, RISØ, TEKES, UKAEA).

Further details of the work of the individual national research institutes are provided in the series of fiche in Annex 1.

3.4 LESSONS LEARNED

3.4.1 Many lessons have been learned from the Fusion Programme of which the following three of particular importance:

- Large, long-term R&D projects require strong and constant sponsorship and high profile and competent leadership. In the past, the European Union (and some Member States) have given such sponsorship to the Fusion Programme and, in particular, to JET. This allowed the programme management to exploit the Programme very effectively.

  ITER, in its highly international configuration (which has inevitably introduced complications both at the strategic and management levels), seems to have progressively lost sponsorship, despite the excellent work done by the entire ITER team. The US withdrawal from ITER (1998) and the financial crisis in the Russian Federation have led to the requirement to redesign a lower cost New-ITER with less ambitious objectives. Moreover, international uncertainty still exists.

- Such long-term, challenging and costly programmes, require a firm, stable and powerful legal framework within which to be managed. Again, the JET experience is meaningful and, with the obvious adaptations to the new context, a legal framework with greater management responsibilities coherent with the requirements of the Next Step will have to be adopted.

- The fusion community has always stressed the differences between fission and fusion in terms of safety and environmental impact, and all the studies done in the recent years confirm this point. Nevertheless, the general public still tends to view the two technologies in the same light. More attention is required on this issue.

3.5 RELEVANCE

3.5.1 The FP5 objectives continue to provide a scientifically and politically coherent fusion programme. No changes to the objectives are considered necessary for the remainder of FP5.

4 Conclusions

4.1 During the last 5 years, the programme has achieved very important results (see Section 5), confirming fusion should now be considered as a credible option in the search for clean, large-scale power generation systems that are going to be required to provide a future sustainable energy supply. Nevertheless, there are still a number of important scientific, technological and engineering issues to be addressed before a commercial power plant can be realised. At least two more generations of machines are envisaged before building a prototype reactor and, based on present planning, large-scale electricity would be produced in around 50 years. Recent history has shown how sensitive the Programme is to delays in the decisions. The postponement of the construction of ITER has already introduced a delay of almost 10 years.

4.2 From the organisational and programme point of view, the last two years have been particularly complicated for the Fusion Programme due to the need for new organisational structures and framework agreements and due to the high level of uncertainty regarding the ‘Next Step’. The Board’s impression is that, in spite of this situation, the programme has been well co-ordinated and efficiently run by the Commission as shown by the obtained results.

4.3 The European Fusion Programme has helped to place European science, technology and industry at the leading edge of development in this sector. The programme provides a good example of scientific development leading to the further development of industrial capabilities. Europe now has by itself all the required technical, engineering and industrial capabilities to proceed to the ‘Next Step’ and take the fusion programme forward.

5 Programme Specific Issues

5.1 FUTURE GLOBAL ENERGY SCENARIOS

5.1.1 Future long-term energy scenarios show a steady increase in world-wide energy demand driven by the increase in the global population and the rapid growth in energy consumption per capita in the developing economies. Although considerable savings in energy resources can be achieved by the development of more efficient supply and demand technologies, these alone are unlikely to be able to meet future requirements. Hence, it is essential that a full range of alternative energy options is investigated.

5.1.2 In parallel to the growth in demand for energy, there is an increasing understanding of the environmental impacts of energy such as the climate change impacts of the continued burning, globally, of finite fossil fuel resources. Consequently, the need for new non-polluting forms of energy is growing and substantial Community and national financial resources are being deployed to meet this challenge. Renewable energy is a reality but issues exist associated with its availability, location and integration into the network for the provision of large-scale power in major industrial cities. Nuclear energy, both fission and fusion, are CO_2 emission-free alternative energy options for the provision of high energy density. Nuclear fission is already available but there are concerns about its safety and the issues associated with the disposal of long-lived radioactive waste. Nuclear fusion still requires further research and long-term development but appears to have the potential to provide a safe and clean alternative. Future energy demand will not be met by a single source but will be met by a mix of sustainable energy resources. To achieve this will require a long-term energy policy and a substantial increase in our level of knowledge.

5.2 THE DIFFERENT STEPS TOWARDS A FUSION REACTOR

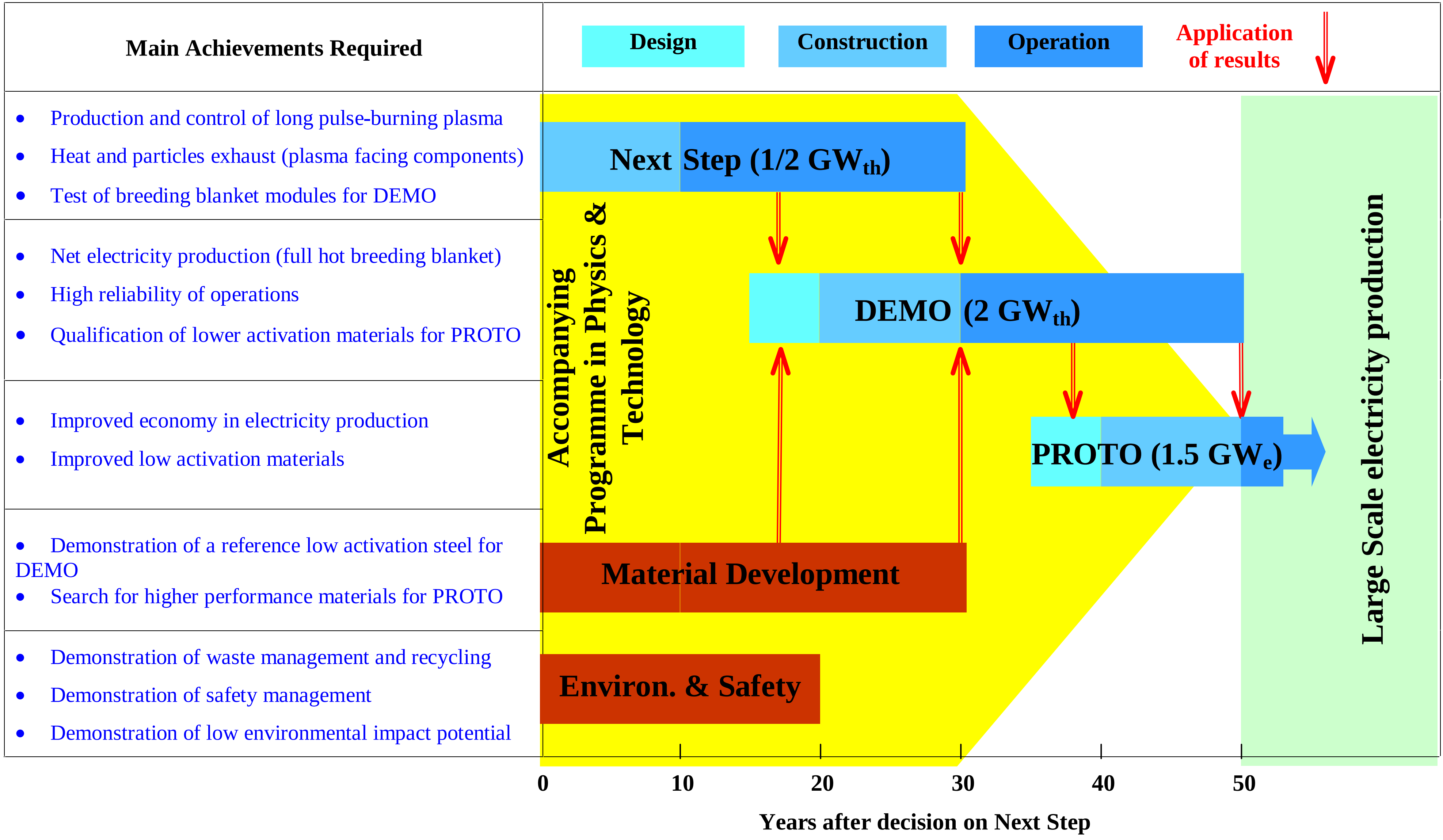
5.2.1 The European Fusion Programme is envisaging two major steps before a prototype reactor, as shown in the tentative roadmap in Figure 6. Each step should, at least, meet the specific achievements listed in the figure. It is envisaged that each step in the development will require at least one major machine, although ideally more than one would be built to provide supporting studies and confirmatory evidence.

5.2.2 Due to the level of public concern over nuclear power it will also be important to demonstrate as quickly as possible the waste management and sustainable recycling required by fusion power and to demonstrate safety management. Hence, this is shown as a separate activity on the roadmap, scheduled for completion before the construction of the DEMO machine.

5.2.3 In addition to the major steps, described above, a materials research programme is necessary to develop higher performance, low activation materials for DEMO and PROTO. This is likely to require a large-scale materials test facility. This was recommended in the previous 5 year assessment but as yet there is no commitment towards its construction either at an International or European scale.

5.2.4 The long time-frame (Figure 6) necessitates a long-term, coherent R&D programme. The programme must be based on sound management, with well defined milestones and decision points whilst maintaining sufficient adaptability to enable the programme to accommodate future uncertainties associated with the evolutionary process (scientific, technical and political).

Figure 6: Tentative Roadmap of Achievements starting from the decision to construct the Next Step



6 Recommendations for the future

6.1 The European Fusion Programme has helped to place European science, technology and industry at the leading edge of development in this sector and this advantage should be defended and possibly increased.

6.2 The European Fusion Programme should continue to be reactor orientated and the construction of the 'Next Step' should be started in FP6. This should be the first priority and some of the budget should be specifically earmarked for the Next Step. The budget should be at least at the present level, although a constant budget may lead to a reduction in the funding available for the other activities. If the budget continues to remain at the same level in FP7 and FP8, the Board believes it will still be possible to finance the completion of the construction of the Next Step, provided there is a reorientation of the activities in the national research institutes.

6.3 To proceed with the 'Next Step' in the international collaboration perspective of the New-ITER, the European Union should within the next 2 years:

- Conclude negotiations on the legal and organisational structure of the future venture
- Actively seek a European site for the New-ITER, since this is the best option from a European viewpoint.
- Conduct a thorough review of the financial issues, including the different financial costs and benefits of siting it in Europe, Canada or Japan, and establish the extent to which Japan would support the construction of New-ITER outside Japan.
- Examine in detail the recent interesting expression of interest received from the Canadian Consortium.

6.4 In the same 2 year period, due to the uncertainty over the outcome of the international negotiations, Europe should study an alternative to New-ITER, which would be suitable to be pursued by Europe alone. For example, a copper magnet machine which would still achieve the required objective of demonstrating a burning plasma under reactor conditions even if this would delay the integration of the superconducting technologies. Europe would then be ready by mid FP6 to drive forward the development of fusion even in the event of a further lack of positive decision on the construction of the New-ITER.

6.5 In the meantime, in FP5, limited investment on JET should be allowed to exploit the full value of the machine. This will also enable the fusion community to further prepare for the operation of the 'Next Step'.

6.6 The Fusion Programme, as part of a long-term sustainable energy policy, is highly demanding from a political and operational viewpoint and requires renewed support from the political authorities with an explicit endorsement of the tight timescale suggested for the 'Next Step'.

In view of the Programme's evolution to a more managerial phase, a more innovative operational solution should be studied, to be approved together with

FP6. There are several alternatives, such as an agency in charge of the entire fusion programme (and EFDA could be considered as a first step) or a legal entity belonging to Euratom, to be responsible for the implementation of the Next Step including the management of the money earmarked for this specific objective. In any case, the Committee structure governing the fusion programme should be streamlined.

6.7 Following a positive decision on the construction of the Next Step, a refocusing of the European Programme will be required. For this purpose, a critical assessment of the different European machines and their funding should be undertaken.

6.8 A Materials Research Programme is necessary to develop high performance, low activation materials for machines after the ‘Next Step’. This programme should be run in parallel with the ‘Next Step’ to ensure the materials are ready when required and should include new materials concepts. It is recommended that international discussions on a 14 MeV neutron source Materials Testing Facility or alternative testing solutions are brought to a decision on a timescale consistent with reactor development.

6.9 The public acceptance of fusion is a key factor in its development as an energy option. Concern on this point has been expressed in several of the recent annual monitoring reports for the fusion programme despite increased effort on the safety and environmental aspects of fusion. Environmental issues should be considered as a full programmatic action, using a broader and more structured approach, in parallel to reactor development (Figure 6). The programme should continue to address issues such as fuel cycle management, waste management and recycling and all the safety aspects. In the short-term, a small Working Group could be set up to review the safety and environmental results obtained to date and to actively promote the benefits of fusion power to a broad range of political and public stakeholders.

6.10 There are various examples where there has been the transfer of technologies, skills and experience from the fusion programme to other areas of science and technology, and evidence for the transfer of know-how and experience to European industry. Such transfers should be exploited in a more structured and entrepreneurial way in response to market demand.

Programme of Visits/Meetings

Date	Place	Associations / Organisations	Participation
28 September 1999	Brussels (B)	• European Commission / DG Research	Full Board
12/13 October 1999	Abingdon Culham (UK)	• Euratom – UKAEA Association • JET Joint Undertaking	Full Board
2/3 November 1999	Cadarache (F)	• Euratom – CEA Association	Full Board
30 November 1999 afternoon	Brussels (B)	• European Commission / DG Research • European Energy Foundation – Dinner-debate	Prof. Airaghi Dr. Berry Dr. Rebut Prof. Condé
10 December 1999	Madrid (ES)	• Euratom – CIEMAT Association • Euratom – IST Association	Prof. Matos Ferreira Dr. Ing. Newi Prof. Condé
20 December 1999	Frascati (I)	• Euratom – ENEA Association	Full Board
10 and 11 January 2000	Garching (D)	• Euratom – IPP Association • Euratom – Greece Association • Euratom – ÖAW Association • ITER – Joint Central Team • EFDA – Close Support Unit	Full Board except Dr. Ing. Newi
17 and 18 January 2000	Jülich (D)	• Euratom – FZJ Association • Euratom – Belgian State Association • Euratom – FOM Association	Prof. Condé Dr. Rebut Prof. Stoneham
27/28 January 2000	Brussels (B)	• European Commission / DG Research	Full Board

18 February 2000	Helsinki (SF)	• Euratom - Ris∅ Association • Euratom – NFR Association • Euratom – TEKES, NTA Association	Prof. Condé Dr. Ing. Newi Dr. Rebut
2 March 2000	Brussels (B)	• Euratom – FZK Association • Euratom – Swiss Association	Full Board except Prof. Airaghi and Prof. Stoneham
3 March 2000	Brussels (B)	• European Commission / DG Research	Full Board
24 March 2000	Brussels (B)	• European Commission / DG Research	Full Board
14/15 April 2000	Rome (I)	• European Commission / DG Research	Prof Airaghi Dr Ing Newi Dr Rebut Dr Berry
27/28 April 2000	Brussels (B)	• European Commission / DG Research	Full Board

Glossary of Acronyms

CCE-FU	Consultative Committee Euratom-Fusion
CCFP	Consultative Committee for the Fusion Programme
DEMO	DEMOnstration reactor
EDA	Engineering Design Activities for ITER
EFDA	European Fusion Development Agreement
EURATOM	EURopean ATOMic energy community
FDR	Final Design Report of ITER
FP5	Fifth Framework Programme
FP6	Sixth Framework Programme
IEA	International Energy Agency
IFMIF	International Fusion Material Irradiation Facility
IAM	Intermediate Aspect ratio Machine
ITB	Internal Transport Barrier
ITER	International Thermonuclear Experimental Reactor
JET	Joint European Torus
JIA	JET Implementing Agreement
JOC	JET Operating Contract
JRC	Joint Research Centre
NET	Next European Torus
Q	Fusion power gain
RAFM	Reduced Activation Ferritic-Martensitic
RTD	Research and Technological Development
RTO/RC	Revised Technical Objectives/Reduced Cost of ITER
S&E	Safety & Environment
SERF	Socio-Economic Research on Fusion
SWG	Special Working Group
TAC	Technical Advisory Committee
$ß_N$	a dimensionless quality factor giving a measure of the plasma pressure which can be reached under stable conditions

ANNEX 1: National Research Institute Fiche

ASSOCIATION EURATOM/CEA - Commissariat à l'Energie Atomique

Contract Nr. : 344-88-1 FUA (F)ERB 5000 CT 910001
Period : 01/01/1988 - 31/12/2000

Research Unit : Département de Recherches sur la Fusion Contrôlée

Centre d'Etudes de Cadarache
Boîte Postale 1
F-13108 Saint-Paul-lez-Durance

History of Association/Laboratory
- Created in 1958 as Service de Recherches sur la Fusion Contrôlée.
- Operated the TFR Tokamak at Fontenay aux Roses for 11 years.
- PETULA and WEGA were constructed and operated at Grenoble.
- Research Unit moved to Cadarache in 1984-1986.
- First operation of TORE SUPRA in April 1988.

Present scientific and technical programme
- Operate the TORE SUPRA superconducting Tokamak
- Investigate long pulse operation of high-performance steady state discharges
- Prepare the next step :
  - superconducting magnet development,
  - plasma facing components,
  - (ergodic) divertor physics,
  - negative ion beam and ECRH development,
  - current drive and current profile optimisation,
  - tokamak system operation and control,
- Technology :
  - tritium breeding blanket,
  - structural materials,
  - high heat flux components, baffles, limiters,
  - electron gun tests,
  - remote handling
  - safety.

Achievements during the last 5 years
- Long energetic discharges: 280 MJ with 2.4MW injected and extracted power during 120s (world record).
- Non-inductive full current drive discharges: 70s with multiparameter feedback control (2.5 MW of LH power at 3.7 GHz).
- Enhanced Performance discharges by current profile control (LHEP mode).
- Demonstration of favourable properties of the ergodic divertor concept (low plasma edge temperature, high radiation rate mantle, impurity screening, edge confinement barrier).
- Developments of next step relevant technologies:
  - ❖ Superconducting cables and connexions for the ITER TF Model Coil.

- Actively cooled Plasma Facing Components developments for Tore Supra and ITER (10 to 20 MW/m^2 explored).
- Operation of a "single gap" negative ion based neutral beam injector at 950 keV.
- Successful test of a steady state LH launcher on Tore Supra.

Staff (CEA + Euratom) at Cadarache :	Professionals	161
	Support staff	143

Yearly budget (expenditure 1999) about 57 Mio EURO

Management Structure

Head of Research Unit: J. JACQUINOT, Deputies: M. CHATELIER, B. TURCK
STEP (Operation) Head: D. VAN HOUTTE Deputy: J. HOW
SIPP (Edge Plasma) Head: A. GROSMAN Deputy: G. REY
SCCF (Core Plasma) Head: B. SAOUTIC Deputy: C. LAVIRON

Status: February 2000

ASSOCIATION EURATOM/CIEMAT -
Centro de Investigaciones Energéticas, Medioambientales y Tecnológicas

Contract Nr.:	EUR 349-90-1 FUA (E)
Period:	1/1/1990-31/12/2000
Research Unit:	CIEMAT Avenida Complutense 22 E-28040 Madrid

History of Association

The Association EURATOM/CIEMAT was established on January 1, 1986.

Present scientific and technical programme

- Scientific exploitation of flexible heliac TJ-II
- Development of plasma diagnostics
- Theoretical studies
- Participation in technological programme and NET/ITER
- Participation in the exploitation of the JET facilities
- ICF "keep in touch" activities

Achievements during the last 5 years

- Successful construction of Stellarator TJ-II below budget.
- Measurement of vacuum flux surfaces in excellent agreement with theoretical predictions for TJ-II.
- TJ-II start up and experimental demonstration of TJ-II flexibility.
- Development and operation of a sophisticated set of plasma diagnostics.
- Development of theoretical tools for interpretation of 3D configurations.
- Transport and turbulence studies in different magnetic configurations.
- Development of understanding of radiation induced effects upon different materials.
- Specification and design of diagnostics for ITER.
- Cession of TJ-IU torsatron to University of Kiel.

Staff

Professionals:	70
Support staff:	50

Yearly budget (expenditure 1998): about 12 MioEURO

Management structure

Head of Research Unit: C. ALEJALDRE
(Director Laboratorio Nacional de Fusion por Confinamiento Magnetico)

Status: February 2000

ASSOCIATION EURATOM / Confédération Suisse

Contract Nr: 341-88-1 FUA (CH) (ERB 5000 CT 890018 007)
Period: 01/01/1989 - 31/12/2000

Research Unit: Centre de Recherches en Physique des Plasmas (CRPP)
Ecole Polytechnique Fédérale de Lausanne (EPFL)
PPB-Ecublens
CH-1015 Lausanne

History of Association/Laboratory:

•1961: created as a Plasma Physics Research Institute attached to the Swiss National Foundation
•1973: integrated in the Ecole Polytechnique Fédérale de Lausanne (EPFL)
•1979: became associated to EURATOM
•1993: integration of the group in fusion technology of the Paul Scherrer Institut, Villigen

Present scientific and technical programme

• Tokamak physics and gyrotron development
• Tokamak TCV started operation in November 1992 with the objective to study strongly non-circular and elongated plasmas
•Exploitation of 3.0 MW ECRH on TCV plasmas
•Installation of the remaining ECRH power (total power: 4.5 MW)
• Theory concentrated on the numerical study of the stability of toroidal configurations, RF heating, current drive and transport
• Plasma-wall interaction (with the University of Basel, Switzerland)
• SULTAN facility: superconductor development; superconducting magnet technology
• PIREX: low activation materials development and test

Achievements during the last 5 years

- TCV achieved a record plasma elongation of κ=2.64 for an ITER-like aspect ratio tokamak.
- TCV showed that the beta-limit decreases with high elongation, confirming our earlier ideal MHD predictions.
- TCV achieved a fully non-inductive plasma current of 123kA for 1.9 seconds using 1.5MW ECCD.
- TCV explored the shape-dependence of energy confinement in Ohmic and ECH plasmas, leading to better understanding of current profiles and sawtoothing over a wide range of plasma elongation and triangularity.
- We recorded a record energy output for a high frequency gyrotron, 400kW for 15.5s at 118GHz, developed in a European collaboration between Associations and industry.
- We developed gyro-kinetic codes capable of exploring the causes of anomalous transport in tokamaks and later in stellarators.
- We continued the development of numerical models for exploring novel 3-D magnetic confinement configurations.

- In our unique SULTAN facility we tested long cable lengths of high current 100 kA cable-in-conduit- superconductors developed world-wide and we used the experimental results for engineering code validation.
- We radiation tested OPTIMAX, a class of promising new material (ferritic martensitic steel) for future reactor construction, developed under a collaborative agreement with industry.
- We collaborated actively in many international partnerships, especially JET and ITER.

Staff Professionals: 54
Support staff: 54

Yearly budget *(expenditure 1998)* about 17 Mio Euro

Management structure
Head of Research Unit: Professor M.Q. TRAN
UHD (Unité Hors Département) of the Ecole Polytechnique Fédérale de Lausanne

Status: February 2000

ASSOCIATION EURATOM/DCU - Dublin City University

Contract Nr. : ERB 5004 CT 96 0011
Period : 19/08/1996 - 31/12/2001

Research Unit: Irish Research Unit consists of research groups at :

DCU-PS (School of Physical Sciences)
DCU-MS (Department of Mathematical Sciences)
UCD (School of Mathematics)
DIAS - (Dublin Institute for Advanced Studies)
UCC-P (University College Cork - Department of Physics)
UCC- EEM (Department of Electrical Engineering and Microelectronics)

History of Association/Laboratory

Co-ordinated fusion activities started in 1989 with the awarding of three contracts to conduct cost-sharing actions. The number of contracts and their work grew steadily from there leading to the setting up of an Association in August1996.

Overview of Scientific and Technical programme

- DCU-PS:	Negative ion source development (in association with CEA-Cadarache) Plasma diagnostics, computational physics and plasma surface interactions
- DCU-MS:	Mathematical modelling of resistive MHD instabilities (in association with Dundee University and CEA-Cadarache)
- UCD/DIAS:	Theoretical and computational work on: ion cyclotron harmonic mode excitation, nonlinear Alfvénic structures in MHD, cross-field diffusion and field-line wandering
- UCC-P:	Investigation of high Z impurity and MARFE spectra in JET Spectroscopy of the COMPASS Tokamak (at UKAEA-Culham)
- UCC-EEM:	Faraday rotation polarimetry for the RFX machine (in association with IGI-Padova) Extension of the FIR Interferometer on the TCV machine to a Faraday rotation polarimeter (in association with CRPP-Lausanne) Computation studies and numerical modelling of plasma diagnostic data (with IPP)

Achievements during the last 5 years

DCU –PS - Determined a resonant energy exchange between argon and hydrogen leads to an increase of vibrationally excited molecules in the argon/hydrogen mixture. An experimental run was carried out on the KAMABOKO source on MANTIS in CEA Cadarache to carry out optical emission spectroscopy on the filament driven discharge. Local measurements of the rf electric field and current density have been made and the plasma conductivity deduced which allowed the confirmation of the importance of the anomalous skin effect and collisionless heating.

UCC-ASL - Work has continued towards building up a database which will enable high Z elements to be identified promptly when they enter fusion plasmas. A SPRED survey spectrometer and a CCD^2 X-ray spectrometer have been prepared for use on MAST where they will be used to monitor impurities.

UCC-EEM – For the first time multichord FIR polarimetry measurements have been performed in the RFX experiment. Reliable results have been obtained for plasma currents between 0.5 and 1MA and a scaling of the measured faraday rotation angle with the average poloidal B field has been demonstrated.

UCC-P – CLISTE code: Successful identification of current density profile on ASDEX Upgrade high-performance discharges with Internal Transport Barrier. Fast Identification of Stellarator Equilibria on W7-AS: Database studies to identify limits of pressure profile identification using magnetics. EFIT-TRANSP consistency checks underway at JET.

UCD-DIAS - Study of strange kinetics in Hasegawa-Mima turbulent transport. Study of transport regimes in anisotropic magnetic turbulence.

Staff

Professionals :	about 18 MY in 1999	(Number of Professional Staff : 28)
Support staff :	about 6 MY in 1997	(Number of Support Staff : 22)

Overall expenditure :about 0.9 MioEURO/year

Management Structure

Head of Research Unit:	Prof. E.T. Kennedy,	Tel: (353) 1 704 5305
	Dublin City University,	fax: (353) 1 704 5384
	Glasnevin,	E-mail:eugene.kennedy@dcu.ie
	EI - DUBLIN 9	

Status: February 2000

ASSOCIATION EURATOM/ENEA -
Ente per le Nuove tecnologie, l'Energia e l'Ambiente

Contract Nr. : 343-88-1 FUA (I) ERB 5000 CT 880031
Period : 01/01/1988 - 31/12/2000

Research Units of ENEA :

Centro Ricerche Energia
ENEA
Via E. Fermi 45
I-00044 Frascati

Centro Ricerche Energia
ENEA Brasimone
I-40032 Camugnano

Centro Ricerche Energia
ENEA Bologna
Via Martiri di M. Sole 4
I-40129 Bologna

History of the EURATOM-ENEA Association
Started 1959 as a Subassociation to Euratom-CEA, which then became the Euratom-ENEA Association in 1960. It pioneered in the '60 very high density and inertial confinement fusion schemes. From the 70's the program was prevalently devoted to tokamaks research and related technologies.

Present scientific and technical programme
- Magnetic confinement studies, centered on the exploitation of the Frascati Tokamak Upgrade and JET facilities.
- Fusion technology, NET/ITER related programmes (Superconductivity, Remote handling, Plasma Facing Components, Safety, various tasks, etc.), and Long Term programs (Blanket, Materials, Neutron Source, etc.).
- Frascati Neutron Generator : 10^{12} n/s.
- Inertial confinement studies : Laser ABC system. Keep-in-touch activity with the international research programme on inertial confinement.

Achievements during the last 5 years
- Demonstration of high efficiency of Lower Hybrid Current Drive at high plasma density. Demonstration of temperature dependence of Lower Hybrid Current Drive.
- Investigation of global transport properties of ohmic regimes at density and magnetic field values relevant for ITER.
- Achievement of enhanced confinement regimes with deep pellet injection and weak/negative magnetic shear profiles. Analysis of the effect of the MHD activity on transport in these regimes.
- Investigation of plasma transport in very high electron temperature plasmas (Te of the order of 15 KeV) produced by Electron Cyclotron Resonant Heating.
- Influence of high Z wall materials on tokamak operations.
- Analysis of shear flow formation induced by Ion Bernstein Waves injection.
- Development of hybrid MHD/ Gyrokinetic codes and analysis of instabilities driven by energetic particles (TAE, Fishbones etc...).
- Development and characterisation of superconducting coils for ITER in collaboration with industry.

- Fabrication of the first European Nb3Sn, 12T, superconducting coil with an ITER relevant Cable-in Conduit conductor. Tests and demonstration of the dynamic response of the coil in ITER conditions.
- Development of high temperature superconducting cables.
- Frascati Neutron Generator: improvement of the nuclear data library and validation of the shielding performances of the ITER blanket design.
- Materials: development of joining, plasma spray, non destructive examination techniques for plasma facing components; development and characterisation of SiC/SiC fiber composites.
- Fabrication and operation of the Divertor Test Platform and Divertor Refurbishment Platform in order to validate the design and remote maintenance procedure of the ITER divertor.
- Inertial Confinement Studies:
  Experiment: stable acceleration of thin (a few micrometers) foils over distance about 70 times the in-flight-foil-thickness.
  Theory: formulation of new ICF schemes different from the standard ones.

Staff
Professionals : 150
Technical staff : 165

Yearly budget (expenditure 1999): about 60 MioEURO (including the Milano and Padova/ CNR Research Units)

Management structure
Head of Research Unit : R. ANDREANI
The Fusion Division of the ENEA's Energy Department includes three Units : Physics, Technology, Experimental Engineering subdivided in Projects, Sections and Special Units. Management is assisted by a special Support Unit. Universities and other ENEA Units are contributing to the programme through subcontracts.

Status: February 2000

ASSOCIATION EURATOM-ENEA Consiglio Nazionale delle Ricerche, CNR – Milano

Contract Nr.: 343-88-1 FUA (I) ERB 5000 CT 880031
Period: 01/01/1998 – 31/12/2000

Research Unit Istituto di Fisica del Plasma "Piero Caldirola"
Associazione Euratom/ENEA/CNR
Via R. Cozzi, 53
I-20125 MILANO

History of Association/Laboratory
-Laboratorio di Fisica del Plasma del CNR, date of foundation 29.1.70.
-Istituto di Fisica del Plasma: foundation 20.12.1979.
-Association EURATOM/ENEA/CNR: 1-1-1983 onwards.

Present scientific and technological programme
1) ECRH experiment on FTU Tokamak (ENEA Frascati) at high density, in collaboration with the ENEA, Centro Ricerche Energia, Divisione Fusione: the plasma will be heated at 140 GHz, 2 MW for 0.5 s by microwave power.
2) Fusion Technologies: Study of the effects of plasma-wall interaction, in fusion reactor, by metal surface analysis (XPS; SIMS). Study of the effects on different ion impurities by Radiofrequency produced ponderomotive forces.
3) Theoretical research on: Wave-plasma interaction and non linear wave phenomena, support to the ECRH experiment on FTU; Transport and MHD Physics; Advanced wave plasma-problems.
4) JET (EFDA) activity: studies on the development of compensation coils for "error field" control on JET. Participation to the activity of the S2 Task Force on JET on the study of heat pulses and thermal barriers. Participation to the Task Force M on JET on the study of neo tearing modes. Participation to the Task Force H on JET (RF Heating)
5) ITER Activity: Participation to Tasks for the development of ECRH system for ITER.

Achievements during the last 5 years

ECRH experiment on FTU Tokamak (ENEA)

- Installation and operation of a system of four gyrotrons at 140 GHz (2 MW total), for ECWH experiments.
- Experimental results: full stabilisation of sawtooth instability in FTU with localised off-axis ECRH, proof of the consistency of response of saw-tooth instability to localised ECRH/ECCD with a critical shear model, obtaining of neoclassical ion energy transport regime with ECRH at high density, ECRH induced destabilisation of isolated and coupled tearing modes, achievement of high Te, up to 14 KeV, in discharges with low/inverted central shear.
- Identification of kinetic effects in electron energy distribution function at very high Te, with strong central ECRH.
- Specific diagnostic and computational tools for the measure and analysis of residual EC radiation at the vessel walls.

- Operation of an equipment for a fully automatic pattern measurement of large-size ECRH launchers; development of test-sets and laboratory equipment for phase-amplitude measurements of components/systems in the millimetre wave frequency band; operation of high power calorimetric matched loads for millimetre wave beams; development of passive microwave components, for 140 GHz, high power.

Fusion Technology

- Tritium recovery from Tritiated water by use of getter alloys; design of getter Reactor for recovery of Tritium from tritiated water, (ITER); methods of cryogenic separation for exhaust mixtures of Fusion reactors.
- Plasma device for application of ponderomotive forces to ion plugging.
- Development of diffusion liquid sodium pumps for NET.

Theory of plasmas and thermonuclear Fusion

- Development of the theory and codes for the propagation, power absorption, and non inductive current drive of Gaussian beams of EC waves in toroidal plasma confinement devices, including self diffraction effects.
- Development of codes for the design and interpretation of Collective Thomson scattering in tokamaks.
- Theory of the nonlinear interaction of intense short wavelength wavepackets with plasmas with results in the study of self channelling effects, ionisation instabilities and generation of high harmonics.
- Theory of electrostatic response of electron-ion plasma to ponderomotive effects of intense electromagnetic waves.
- Theory of nonlinear response to external fields and of the evolution of isolated and coupled rotating tearing modes in tokamaks, with identification of the role of the ion polarisation current and of the density scaling for the threshold of locked modes instability in presence of toroidal rippled field.
- Theory of the response of sawteeth and neoclassical tearing modes to localised E.C. Heating current drive, applied to the interpretation of tokamak experimental results and to scenarios of feedback control.
- Theoretical models of transition to stochasticity of magnetic configurations with singular lines.
- Development of interpretative models of nonlocal transient heat propagation, with sign reversal of heat pulses; identification of transport barriers in tokamaks.
- Development of interpretative tools for the diagnostic of the neutron emission spectrum in tokamak reactors.

Staff: Professionals: 20 Support Staff: 19 External professional Collaborators: 5

Management Structure: Head of the Research Unit: G. LAMPIS
Status: February 2000

EURATOM/ENEA (Consiglio Nazionale delle Ricerche, CNR - Padova)

Contract Nr. : 343-88-1 FUA (I) ERB 5000 CT 880031
Period : 01/01/1988 - 31/12/1999

Research Unit : Consorzio RFX
Corso Stati Uniti 4
I-35127-CAMIN PADOVA

History of Association/Laboratory

-Association Euratom/CNR : Contracts 46/76/I/FUAI; 54/79/I/FUAI; 102/82/I/FUAI.
-Association Euratom/ENEA (CNR) : Contracts 202/85/I/FUAI; 343/88/I/FUAI actual contract.
The activity of the Padua group for fusion research increased substantially in 1984 after the start of the RFX (Reversed Field Pinch eXperiment) project. The RFX construction was completed in 1991; the first RFP plasmas were obtained in 1992. Since then, the device was routinely operated by alternating experimental periods (for a total of 12.000 power pulses) and shutdown periods to install new or modified equipment.

Present scientific and technical programme
The present scientific program is mainly focused on the exploitation of the RFX experiment in a wide range of operational regimes, to perform studies on particle and energy transport, radiative losses, magnetic dynamics, plasma wall interaction. Plasma diagnostics are progressively improved to obtain higher accuracy and better time and space resolution. Technological developments are mainly oriented to increase the capability of actively control the plasma and the plasma - wall interaction phenomena. The Research Unit is also participating in the ITER Design and in JET operation.

Achievements during the last 5 years
- Extended range of plasma currents (up to 1.2 MA); clean discharges in the whole current range (Z_{eff} <1.5)
- Better space and time resolution of plasma diagnostics, giving a deeper understanding of transport phenomena
- New techniques to control the field configuration by fast amplifiers
- Rotation of tearing modes induced by external fields: experiments and modelling
- Improved confinement by pulsed and oscillating poloidal current drive
- Theoretical prediction and clear experimental evidence of quasi-single helicity states, both transient and stationary

Staff
Professionals : 60
Support : 55

Management structure
Head of Research Unit : F. GNESOTTO

Status: December 1999

ASSOCIATION EURATOM/Etat Belge-Belgische Staat
(Ecole Royale Militaire/Koninklijke Militaire School)

Contract Nr. : 346-88-1 FUA (B) ERB 5000 CT 920001
Period : 01/01/1988 - 31/12/1999

Research Unit : Ecole Royale Militaire/Koninklijke Militaire School
Laboratoire de Physique des Plasmas/Laboratorium voor
Plasmafysica
Association "Euratom-Etat belge"/Associatie "Euratom-Belgische Staat"
Avenue de la Renaissance 30
B-1000 Brussels

History of Association/Laboratory
The laboratory was established in 1961 as the research arm of the Chair of Physics of the Royal Military Academy and became a founding member of the EURATOM-Belgian State Association in 1969. It specialised in the study of the propagation of electromagnetic waves in plasmas and the design of appropriate launching structures, highlighted by the development, during 1976-1981, of ion cyclotron heating on ERASMUS, the first university-size tokamak in Europe. In a collaborative effort with the EURATOM-KFA Association, the laboratory conducts since 1981 heating (ion cyclotron) and confinement studies on the TEXTOR tokamak. This collaboration developed in 1996 into the Trilateral Euroregio Cluster of FOM-Rijnhuizen, ERM/KMS-Brussels and FZ-Jülich aiming at an integrated programme of core, edge and exhaust physics centred around the RI-mode, the enhanced confinement state at high radiation fraction discovered on TEXTOR.

Present scientific and technical programme
The programme concentrates on the one hand on the understanding of the influence on tokamak confinement of radiative mantles and edge electrical fields and on the other hand on the advancement of ion cyclotron heating as the heating method for fusion reactors. Theory, diagnostics and technology are developed wherever these aims demand so and support for JET and ITER (through Task Agreements) is of prime concern.

Achievements during the last 5 years
- Discovery of Radiative Improved Mode of tokamak operation in TEXTOR-94 (in close collaboration with the Association EURATOM-KFA).
- Elucidation of role of velocity shear in the suppression of turbulence.
- Further development of ICRH heating systems and codes for plasma heating.
- Development of tokamak start-up and conditioning techniques based on ICRH.
- Development of novel diagnostic techniques for poloidal flow measurements and for the detection of fusion products.

Staff

Professionals : 26
Support staff : 10

Yearly budget (expenditure 1998): 3.135 MioEURO (includes 0.25 MioEURO subcontract with Université Cath. de Louvain)

Management structure

Head of Research Unit : R. WEYNANTS (Director)
Assistant-Director: R. KOCH

Status: February 2000

ASSOCIATION EURATOM/Etat Belge (Université Libre de Bruxelles, ULB)

Contract Nr. : EUR 346-88-1 FUA (B) - ERB 5000 CT 920001 - ERB 5005 CT 99 0104
Period : 01/01/1988-31/12/2001

Research Unit : Unité de Physique Statistique et Plasmas
Université Libre de Bruxelles
Campus de la Plaine, CP 231
Boulevard du Triomphe
B-1050 Bruxelles

History of Association/Laboratory
The Association was founded in 1969: at that time it had two branches:
Ecole Royale Militaire and Université Libre de Bruxelles.
Later, the Centre d'Etude Nucléaire (SCK/CEN) joined the Association.

Present scientific and technical programme
- Theoretical problems of plasma physics in connection with fusion research.
- Transport processes in plasmas.
- Study of plasma turbulence, in connection with transport and heating.
- Numerical simulations of MHD turbulence.

Achievements during the last 5 years
- Development and testing of Hamiltonian maps for field lines and particle trajectories in a general toroidal geometry.
- Derivation of scaling laws for diffusion.
- Neoclassical transport in presence of strong electric fields.
- Implementation of a new numerical technique for MHD turbulence.

Staff
Professionals: 12
Support staff: 1 + 1/2

Management structure
Head of Research Unit: D. CARATI
Deputy: R. BALESCU

Status: January 2000

ASSOCIATION EURATOM/Etat Belge
(Studiecentrum voor Kernenergie/Centre d'Etude Nucléaire, SCK/CEN)

Contract Nr. : EUR 346-88-1 FUA (B) ERB 5000 CT 920001
Period : 01/01/1988 - 31/12/2000

Research Unit : SCK/CEN
Boeretang 200
B-2400 Mol

History of Association/Laboratory

An initial contract of collaboration, on thermonuclear fusion research, between the Association Euratom-Belgian State and the SCK/CEN was concluded on December 22, 1975. In 1982, the SCK/CEN became an associated laboratory.

Present scientific and technical programme
The fusion work at SCK.CEN focuses on *radiation tolerance of materials*: characterisation of neutron irradiated metals (vessel structure, plasma facing components), environmental tolerance of instrumentation for remote handling and diagnostics (ceramics, optical fibres, electronics). This cover also connected items related to safety aspects (reactivity of materials in accidental condition), corrosion (also in collaboration with KULeuven university) and waste management. In the future, SCK.CEN will continue along this main expertise field.
The BR2 material testing reactor and related facilities, as its hot cells equipped for material characterisation, are main assets in the SCK.CEN fusion research programme.
The SCK.CEN manages also the contribution of GRADEL-Luxemburg (divertor maintenance remote handling tools).

Achievements during the last five years
- Overall characterisation of radiation induced degradation of *beryllium*: mechanical toughness, surface reactivity in accidental conditions (hydrogen production), helium production and fracture mechanism modelisation, integrity after thermal annealing, etc. Results contributed to fusion database, and to the SEAL report.
- Characterisation of radiation induced degradation of *stainless steels* (fracture toughness, fatigue toughness), *inconel* (irradiation creep), contributing to the ITER database.
- Identification of several radiation-hardened alternatives to position and force sensors, and to motors, for remote handling units. Significant progress also obtained on *optical fibre* sensors for fibroscopy, strain sensing and optical data link. Preparation of a representative reactor testing of insulation ceramics for heating and current drive.
- More recently, characterisation of alternative reactor materials such as *chromium*, and study of *waste disposal* issues (intrusion scenario), as well as comparison of dismantling strategies on the basis of in-house PWR experience.

Staff

Many SCK/CEN agents participate on a part time basis in the SCK/CEN fusion research programme. The integrated yearly effort is between 10 to 15 professionals and about the same amounts of support staff.

Management structure

Head of Research Unit : M. DECRETON

Status: February 2000

ASSOCIATION EURATOM/FOM - Stichting voor Fundamenteel Onderzoek der Materie

Contract No.: 347-89-1 FUA (NL) ERB 5000 CT 900021
Period: 01/01/1988 - 31/12/2000

Research Unit: FOM Institute for Plasma Physics "Rijnhuizen"
Edisonbaan 14
NL-3439 MN Nieuwegein

History of Association/Laboratory
The Euratom-FOM Association was established in 1962.

Present scientific and technical programme
In the framework of the Trilateral Euregio Cluster (TEC), the Dutch Association concentrates its efforts on the study of the physics of Tokamak turbulent electron transport and non-linear electron dynamics. The experimental work is performed on the TEXTOR-94 facility at Jülich, in particular by means of ECRH/ECCD. Fluctuations are measured by high resolution diagnostics in particular Thomson scattering.
Technology: development of a 1 MW, tunable 130 - 250 GHz Free Electron Maser (FEM) for ECRH/ECCD application in fusion research.

Achievements during the last 5 years
- The development of high resolution diagnostics which made possible:
- The discovery of electron thermal barriers near (but not at) many rational q-surfaces in tokamaks (RTP) and stellarators (TJ-II).
- The interaction of these barriers with magnetic islands and zones with chaotic magnetic field and the influence of these phenomena on turbulent electron transport.
- The creation of filaments under intense ECRH in areas of the RTP plasmas with low magnetic shear as a manifestation of ‘hot snakes’ or ‘positive’ islands, i.e. magnetic structures closed on themselves with very good confinement.
- The occurrence of off-axis sawteeth relaxations in case of negative central shear discharges.
- ECW driven current leading to discharges with 55% non-inductive current.
- The demonstration that with only 5% ECW driven current in counter direction sawteeth can be suppressed as the central q-value is lifted just above 1.
- The demonstration that ECRH could be used to postpone and ameliorate high density disruptions.
- The demonstration that for determination of ECW current drive efficiencies it is necessary to take into account the existence of electron thermal barriers, filaments and islands.
- The direct confirmation in RTP of ASDEX-U observations that the high density clouds around ablating pellets are not in MHD equilibrium and therefore are pushed out of the plasma towards the low field side.
- The preparation for TEXTOR of 5 different microwave diagnostic systems (ECE and reflectometry), a high resolution Thomson scattering diagnostic, a collective Thomson scattering system (together with MIT) for fast-ion distributions and an

innovative ultra soft x-ray camera system for tomography of impurity line emission, this all as contribution to the TEC-programme.

- The preparation of a 110 GHz and a 140 GHz ECRH/ECCD system for TEXTOR as a contribution to the TEC-programme.
- The demonstration of the functioning of the Free Electron Maser as numerically predicted during short pulses(10 μs) of 700 kW at various frequencies between 165 and 205 GHz.
- The construction of a long pulse (hundreds of ms) version of such a FEM with a depressed collector to be tested in spring 2000.
- The education of Ph.D. students in high temperature plasma physics leading to about 20 theses in the period between 1996 and 2000 of which 60% have found a position in the European Fusion Programme.

Staff

Professionals:	30
Support staff:	45
Ph. D. Students:	10

Yearly budget (expenditure 1997): about 11 Mio EURO
(about half of this is for NRG/Petten Research Unit)

Management structure

Head of Research Unit: F.C. Schüller

Status: January 2000

ASSOCIATION EURATOM/FOM (NRG-Petten)

Contract Nr. : EUR 347-89-1 FUA ERB 5000 CT 900021

Period : 01/01/1990 - 31/12/2000

Research Unit : NRG
P.O. Box 25
NL-1755 ZG PETTEN

History of Association/Laboratory

Long standing R&D research in nuclear energy since 1955 (since 1998 as NRG).

Present scientific and technical programme

In Fusion Technology :

- Irradiation and characterisation of fusion relevant structural materials;
- Post-irradiation and reference mechanical testing of various grades of austenitic stainless steel, ferritic/martensitic low-activation steels and advanced alloys;
- Post-irradiation and reference testing of mechanical and physical properties for various advanced ceramic composites;
- Investigation of the reweldability of irradiated stainless steel for ITER and (re)weldability of ferritic/martensitic low-activation steels;
- In-pile measurements of tritium-breeding materials and blanket submodules for ITER/DEMO;
- In-pile permeation measurements of barrier coatings and blanket subassemblies;
- Post-irradiation measurements of tritium retention and release;
- Material research for plasma facing components;

Staff

Professionals : about 10
Support staff: about 15

Management structure

Head of Research Unit : A.M. VERSTEEGH

Status:

ASSOCIATION EURATOM / FZJ - Forschungszentrum Jülich

Contract Nr.: 342-88-1 FUA (D) – ERB 5005 CT 99 0110

Period: 01/01/1988 - 31/12/2001

Research Unit: "Institut für Plasmaphysik" and "Projekt Kernfusion"
Partner in the Trilateral Euregio Cluster (TEC)
Forschungszentrum Jülich (FZJ)
D-52425 Jülich

History of Association/Laboratory
The "Institut für Plasmaphysik" was the first scientific institute of the Forschungszentrum Jülich, founded in the late fifties. The Contract of Association with EURATOM was signed in 1962. During the sixties the programme was focused on theta pinches. In the mid-seventies the activities were re-oriented towards plasma-wall interaction. The central facility for the experimental programme, the tokamak TEXTOR (Torus Experiment for Technology Oriented Research), became operational in 1983 and was upgraded in 1994 by a significant prolongation of the achievable pulse length ("TEXTOR-94").

Present scientific and technical programme
The joint research programme of the TEC-partners aims at developing a coherent concept for energy and particle transport/exhaust under quasi-stationary conditions. The Tokamak TEXTOR-94 ($R = 1.75$ m, $a = 0.5$ m) is equipped with a heating power of 4.0 MW ICRH and 4.0 MW NBI heating (providing a power flux density through the boundary of 25 W/cm²) and with a toroidal pump limiter (ALT-II). Fusion relevant plasmas can be produced and maintained for a duration of up to about 10 seconds. The experiments are accompanied by related modelling activities. Plasma facing materials and components are developed and tested using specific facilities for applying extremely high heat loads.
Highlights of the TEXTOR-94 programme: wall conditioning (boronisation/siliconisation), helium exhaust, edge radiation cooling, impurity transport, RI-mode, runaway electrons, sawtooth-physics, Dynamic Ergodic Divertor (under construction).

Achievements during the last 5 years
- Development and qualification of wall coatings (siliconization, boronization).
- Development and study of the radiative improved mode (RI-mode), which combines improved energy confinement (as good as that of ELM-free H-mode discharges in divertor tokamaks) at high plasma density (at or above the Greenwald density) with energy exhaust on large areas via boundary radiation from feed-back controlled neon or argon or from silicon sputtered from siliconized plasma facing components.
- Development of self-consistent transport code RITM for highly radiative discharges including an explanation for confinement improvements via suppression of ITG-modes. Modelling of poloidal asymmetries with a first fully self-consistent incorporation of drift motions (TECXY).

- Understanding of the trigger mechanism of the radiative instability phenomenon MARFE; with new techniques for suppression of MARFEs densities up to two times the Greenwald density were reached.
- Improvement in the understanding of the sawtooth phenomenon: incomplete reconnection, magnetic amplitude of the precursor mode, modulation of ion temperature and momentum.
- Erosion and deposition studies, in particular using a well diagnosed limiter lock system: prompt re-deposition, comparison of graphite/tungsten, penetration/screening and chemical erosion versus sputtering.
- Recycling and particle control: surface temperature dependence of the emission of H/H_2, dissociation of vibrationally excited H_2 into slow atoms (0.3 eV) and hydrogen (tritium) retention in co-deposited carbon.
- Development of new diagnostics: high resolution x-ray spectrometer, atomic beam for the plasma boundary, run-away detection via synchrotron radiation, recycling studies by laser induced fluorescence.
- Development of the Dynamic Ergodic Divertor as a novel tool to control particle and energy transport at the plasma boundary (to be installed 2000/2001).

Staff
Professionals: 50
Support staff: 70

Yearly budget: about 20 MioEURO

Management structure
Head of Research Unit: U. Samm

Status: February 2000

ASSOCIATION EURATOM/FZK - Forschungszentrum Karlsruhe

Contract Nr. : 350-89-1 FUA (D) ERB 5000 CT 900023
Period : 01/01/1989 - 31/12/2001

Research Unit : Forschungszentrum Karlsruhe (FZK) GmbH
Nuclear Fusion Programme
P.O. Box 3640
D-76021 Karlsruhe

History of Association/Laboratory

Since 1982 Forschungszentrum Karlsruhe participates to the European Fusion Programme as an associated laboratory. The main scope of the contribution is to address the important issues of fusion technology in view of the next experimental reactor to be built and, beyond, related to fusion power reactors. The FZK-Euratom Association, in development cooperation with the Max-Planck-Institute for Plasma Physics (IPP), contributes to the construction of the stellarator WENDELSTEIN-7X. FZK participates in the exploitation of JET.

Present scientific and technical programme:

- ITER related programme (EFDA technology)
  Test and component development for large superconducting magnets (i.a. test of the ITER TF model coil); advanced gyrotron and window development; cryogenic exhaust gas pumping development and prototypic tests; development and test in technical scales of an exhaust gas purification system (Tritium laboratory). Studies on high heat load effects and tritium permeation; design tasks with relevance to reliability and safety of the ITER systems and –plant.
- JET exploitation (EFDA-JET)
  Contributions to fuel cycle and first wall issues, waste management, active gas handling.
- Long term technology (EFDA)
  Breeding blanket development including test modules for ITER, qualification of low activation structural materials, reactor studies with aspects of safety, economy, and influence on the environment.
- Development and construction of the electron cyclotron heating system for WENDELSTEIN-7X in cooperation with University of Stuttgart and European industry.

Achievements during the last 5 years

- Successful test of large superconducting coils (poloial field coil, LCT coil at enhanced field, prototype W7X).
- Highest power (>2MW) and efficiencies ~50% achieved in gyrotrons (ITER, W7X).
- Solid breeder helium cooled blanket developed, engineering design of ITER test blanket.
- Plasma exhaust gas with 10^7 detriation factor demonstrated in technical scale (ITER).
- Qualification of EUROFER steel for low activation / good fracture mech. properties.
- Miniature specimen techniques developed for fusion neutron source (IFMIF).

Staff : 80 pmy/y + 70 support

Yearly budget: about 30 MioEURO/yr

Management structure: Project organisation, matrix structure (project, institutes)

Head of Research Unit : J.E. VETTER

Status: February 2000

ASSOCIATION EURATOM/HELLENIC REPUBLIC

Contract Nr.: ERB 5000 CT 99 0 100
Period: 22/06/1999 - 31/12/2001

History:
A Consultative Committee for Fusion Activities in Greece (CCFA-G) was set up in 1991 with the purpose to co-ordinate fusion activities, when these started being funded by Euratom via cost-sharing actions. In the meantime, fusion activities have developed so that an Association Contract between Euratom and the Hellenic republic was signed on 22 June 1999.

Laboratories, present scientific and technical programme and active collaborations
Physics Programme:

- National Centre for Scientific Research "Demokritos", Institute for Nuclear Technology and Radiation Protection, Athens (N. TSOIS): SOL and divertor physics diagnostics, data base development and simulation (in collaboration with IPP).
- National Technical University, Department of Electrical and Computer Engineering (J. VOMVORIDIS) and University of Athens, Department of Physics (I. TIGELIS): high-power microwaves and plasma/electron beam instabilities, non-linear relativistic dynamics of charged particles, EM scattering (in collaboration with CRPP and FZK).
- University of Ioannina, Department of Physics (G. THROUMOULOPOULOS): negative-energy perturbations, stationary MHD states in magnetically-confined plasmas (in collaboration with IPP).
- FORTH, Institute of Electronic Structure and Lasers, Heraklion (P. LALOUSIS): vapour shield phenomena during hard disruptions, development of codes (in collaboration with IPP).
- University of Thessaly, Department of Mechanical and Industrial Engineering (N. VLACHOS), National Technical University of Athens, Department of Electrical and Computer Engineering (K. HIZANIDIS) and University of Athens, Department of Physics (C. POLYMILIS): MHD turbulent transport, stochastic modelling, transport and chaos and MHD instabilities in fusion plasmas (in collaboration with ULB).

Technology Programme:

- National Centre for Scientific Research "Demokritos", Institute for Nuclear Technology and Radiation Protection, Athens (S. MESSOLORAS): Fracture micromechanisms of ceramic composites and joints under irradiation, brazing with thermomechanical testing (in collaboration with CEA).

Achievements during the last 5 years (before the establishment of the Association)

- Design, construction, installation and operation of a Langmuir probe
- Assessment of radiation modes and beam instabilities in gyrotron beam tunnels
- Construction of equilibria with incompressible plasma flow and derivation of suitable sufficient conditions

Staff (Full-time equivalent, including both physics and technology)
7 Faculty members
7 Ph.D. researchers
10 graduate students, and technicians

Yearly budget (all funding sources): about 1.1 MioEURO

Management structure
Governing body for the administration of fusion activities in Greece: Administrative Committee
Administrator of the Contract of Association: Institute for Nuclear Technology and Radiation Protection of the National Centre for Scientific Research "Demokritos" (Director: M. ANTONOPOULOS-DOMIS)
Head of Research Unit: J. VOMVORIDIS
Participating Institutions: NCSR"D", NTUA, UoA, UoI, FORTH, UoTh

Status: February 2000

ASSOCIATION EURATOM / Max-Planck-Institut für Plasmaphysik (IPP)

Contract Nr.: 339–88–1 FUAD
Period: 01/01/1999 - 31/12/2000

Research Unit: Max-Planck-Institut für Plasmaphysik
Boltzmannstrasse 2
D-85748 Garching bei München

History of Association/Laboratory

The "Institut für Plasmaphysik GmbH" (IPP) was established in 1960 as a shareholding of the Max-Planck-Gesellschaft (MPG) and Werner Heisenberg. In 1971 it became an institute of MPG. IPP has been a EURATOM association since 1961. – With the PULSATOR tokamak experiment (1973 - 1979) IPP succeeded for the first time in penetrating the high-density plasma regime, which is characterised by good confinement properties and low impurity density. The introduction of the new divertor concept in the experiment following, ASDEX (1980 - 1990), brought a further major improvement of the plasma purity which allowed, in 1982, the discovery of a plasma state with enhanced energy confinement (H-regime). This H-mode state is expected to form a sufficient basis for the energy confinement in ITER.
By using model plasmas IPP showed in 1964 that the confinement of a well-built stellarator (WENDELSTEIN Ib), in the collisional regime, is governed by classical losses only. At the same time the importance of resonances was discovered experimentally. In 1980 the WENDELSTEIN 7-A stellarator (1976 - 1986) demonstrated for the first time the possibility of confining a hot plasma just by applying external magnetic fields (without plasma current). A new, improved stellarator confinement concept was discovered and elaborated and forms the basis for WENDELSTEIN 7-X. – IPP hosts the EFDA group and is the European site of the ITER Design Activity.

Present scientific and technical programme

The research programme of IPP is aimed at developing and investigating the basic plasma physics required for a nuclear fusion reactor. For this purpose IPP design, construct, and conduct fusion experiments of the tokamak (ASDEX Upgrade) and stellarator (WENDELSTEIN 7-AS, WENDELSTEIN 7-X) types. The objectives of ASDEX Upgrade, which started operation in 1990, are to investigate divertor configurations suitable for a fusion reactor, to study the core physics and the relation to the edge behaviour (transport, operation limits, MHD phenomena), and to explore advanced tokamak operation. Thus, the results of ASDEX Upgrade will be an important input for the construction of ITER. The WENDELSTEIN 7-AS advanced stellarator, as the first experiment to adopt a modular coil system for magnetic field generation, has achieved clearly improved plasma parameters and confinement properties in comparison with its predecessor, WENDELSTEIN 7-A. These results together with detailed theoretical calculations form the basis for the WENDELSTEIN 7-X stellarator, which is to demonstrate under fusion-relevant plasma parameters and with an optimised magnetic field the physical qualification of a reactor based on the stellarator concept. WENDELSTEIN 7-X is being built in the branch institute of IPP in Greifswald. – Other investigations are concerned with basic plasma-wall interaction, material research, and surface physics.

Achievements during the last 5 years

- quantitative understanding of **ASDEX Upgrade** energy exhaust in different divertor geometries and achievement of strongly reduced target and wall loads due to divertor radiation fractions up to 50% of the input heating power
- progress in the clarification of the connection between core and edge transport; characterisation of different edge operating conditions and clarification of different nature of density limit phenomena in L- and H-mode
- demonstration of efficient pellet injection from the high field side
- formation of stationary internal transport barriers for ion and electron energies, particle and momentum combined with H-mode edge and weak shear for the duration of 40 confinement times and several internal skin times
- performance of weak shear internal transport barrier discharges extended to $H_{ITER\text{-}89P} = 3$ and $ß_N = 2.6$ at higher triangular plasma shapes, still limited by neoclassical tearing modes
- reactor-relevant Te≈Ti > 10 keV operation achieved in internal transport barrier discharges with reversed shear ($q_{min} \approx 2$)
- identification of several new MHD phenomena in both conventional H-mode and advanced tokamak operation
- successful demonstration of feedback stabilisation of neoclassical tearing modes by electron cyclotron current drive (ECCD)
- in the **stellarator W7-AS** demonstration of neoclassical transport properties in the long mean free path collisionality regime; documentation of the role of the radial electric field; discovery of the H-mode in a non tokamak device
- achievement of stellarator plasmas with energy confinement times up to 60 ms, central ion temperatures up to 1.5 keV and central electron temperatures up to 6 keV in W7-AS with plasma radii less than 18 cm
- in high power neutral beam heated W7-AS discharges average beta values up to 2% obtained without indications of instabilities, but close to theoretical stability limit
- ion cyclotron resonance heating successfully applied to heat plasmas on W7-AS and also to sustain plasmas with ICRH only
- development of an island divertor
- development and design of the **stellarator W7-X** device, building construction, procurement of the coil system, preparation of vessel manufacturing, and developments for the power supply and plasma heating systems
- construction of an original-sized superconducting prototype non planar magnetic coil for the new stellarator W7-X device and successful operation in the background field of the European LCT (Large Coil Task) coil (in co-operation with FZK, Karlsruhe)
- investigation of the deposition mechanisms of hydrocarbon radicals and the incorporation of hydrogen isotopes leading to the understanding of layer deposition and hydrogen inventories in fusion experiments

- understanding of the transition from deposition to erosion of plasma facing materials under simultaneous hydrogen and impurity ion bombardment

Staff:	Professionals:	about 300
	Support staff:	about 700

Yearly budget (expenditure 1999 subject to Community support): about 109 Mio Euro

Management structure:

Directorate; Chairman: A.M. Bradshaw	Regulation and supervision of the research programme, internal and external representation
Board of Scientific Directors:	Definition of the research programme
Supervisory Board:	Consultation and supervision of the institute

Status: February 2000

ASSOCIATION EURATOM/IST - Instituto Superior Técnico

Contract Nr. : 418-90-1 FUA (PT)ERB 5000 CT 900029
Period : 01/01/1990 - 31/12/2000

Research Unit : Centro de Fusao Nuclear
Instituto Superior Técnico
P-1049-001 LISBOA

History of Association
Based on the experience acquired during fifteen years of research in fundamental plasma physics, the Centre entered the fusion field in 1986 (theory and reflectometry for ASDEX) and the Association EURATOM/IST was established in January 1990, based on the installation in Lisbon of a small tokamak (ISTTOK).

Present scientific and technical programme
The main projects are:
1) Operation of a fusion experiment in Portugal (ISTTOK)
2) Reflectometry diagnostics for fusion plasmas
3) Plasma engineering systems for fusion devices
4) Studies on non-inductive current drive
5) Studies on transport and MHD activity
6) Participation in the Fusion Technology Programme on materials
7) Keep-in-touch activity in inertial confinement

Achievements during the last 5 years
- Analysis of the electron density profile evolution on ISTTOK "sawtooth-like" discharges by heavy ion beam probing
- Enhancement of the ISTTOK plasma confinement and stability by negative limiter biasing
- Achievement of multi-cycle long duration flat-top alternating plasma current discharges without dwell time on ISTTOK
- Simultaneous measurement of the electron density and temperature in ISTTOK by a heavy ion beam deflection analyser with two species of ions
- Development of a reflectometry diagnostic for density profiles with high temporal as well as spatial resolution in both the high and the low field sides.
- Development of a reflectometry system combining AM and FM techniques for TJ-II
- Development of a "comb" transmitting/reflecting system to estimate the peak density of the JET divertor plasma
- Analytical calculation of the nonlinear frequencies for the unperturbed electrostatic lower-hybrid ray motion
- Development of a fast and accurate Fokker-Planck solver using non-uniform grids
- Development of VME and CAMAC distributed systems for fast timing and event management on MAST
- Development of a VME system for the monitoring of a laser in- vessel viewing system

Staff (in man-years)

Professionals:	53.8
Support staff:	9.4

Yearly budget (foreseen expenditure 1999): about 4 MioEURO

Management structure

Head of Research Unit : C. VARANDAS

Directive Board : C. VARANDAS, J. CABRAL, M.E. MANSO

Status: February 2000

ASSOCIATION EURATOM/NFR - Naturvetenskapliga Forskningsrådet

Contract Nr. : 345-88-1 FUA (S) ERB 5000 CT 900020
Period : 01.01.1988 - 31.12.2001

Research Unit/Laboratories :

The Alfvén Laboratory Royal Institute of Technology S-10044 Stockholm	Department of Physics I and II Royal Institute of Technology S-10044 Stockholm	Studsvik Eco Safe S-61182 Nyköping
Department of Electromagnetics Chalmers University of Technology S-41296 Göteborg	Dept. of Neutron Research University of Uppsala P.O. Box 535 S-75121 Uppsala	Dept. of Atomic Spectroscopy University of Lund P. O. Box 1703 S-22100 Lund

History of Association/Laboratory

After negotiations with Euratom during the years 1974-1976, the Swedish fusion research became formally associated with Euratom in 1976. The Swedish Research Unit consists of geographically separate sub-units, the largest one being the Alfvén Laboratory in Stockholm. The technology program is carried out in Studsvik.

Present scientific and technical programme

- Experimental and theoretical work on the reversed-field pinch and basic confinement physics.
- EXTRAP-T2 received priority status in 1990, operated 1994-8, rebuilt 1999, will start operation in Spring 2000.
- Fusion plasma theory on MHD stability, transport, confinement barrier, RF heating and fast particle physics, with applications to tokamaks and stellarators.
- Studies of plasma-surface interaction.
- Impurity and spectroscopy with fusion plasma physical applications.
- Neutron diagnostics.

Achievements during the last 5 years

- Studies of mode locking and wall locking in EXTRAP T2. Rebuild of T2 (new vacuum vessel, plasma facing wall, new shell with longer magnetic penetration time). Development of DEBS code for simulation of RFP dynamics.
- Studies of wall stabilisation, active feedback stabilisation, and operational limits in advanced tokamaks. Development of first principles models for drift-wave turbulence plasma transport in tokamaks: superior agreement with experimental results (ITER database). Models for L to H transitions and transport barriers. Theory of the global turbulent equipartition distribution in tokamak plasmas. Development of models and codes for ICRH and fast current drive: PENN and $\alpha\kappa$ - model (wave propagation), FIDO (ion velocity distribution), PION and SELFO (self-consistent simulations). Identification of RF-induced spatial transport. Development of models for turbulent transport at the plasma edge and simulation of plasma detachment in the divertor region. New models of sawtooth crashes and resulting fast-ion and impurity redistribution. Theory of alpha particle driven instabilities in tokamaks (TAE modes, fishbones, ion cyclotron emission).

- Measurements at TEXTOR and analysis of fluxes of D and impurities in the SOL, and retention of D and neon. Analysis of plasma facing components at JET.
- New analysis techniques and measurements of Z-effective electron temperature based on VUV spectroscopy in the RFP experiments. Measurements of impurity density radial profiles and impurity toroidal rotation velocity. Data base for low Z elements used for JET divertor modelling.
- MPR 14 MeV neutron spectrometer (priority support) on line in JET throughout 1997 including the tritium experiment: 3000 discharges recorded, neutron spectrum of triton burn up in D plasmas measured, measurements at the 10 ms resolution level in DT plasmas with NBI and ICRH heating, Doppler shifts in spectra corresponding to toroidal rotation velocities 600 km/s. TANSY 14 MeV neutron spectrometer on line (JET) during DT experiments: measurements of ion temperature anisotropy during ICRH. ToF 2.45 MeV spectrometer: measurements of T_i.
- The underlying technology programme is mainly focused on fusion safety and environment issues: modelling of loss of coolant accident transients; analysis of the behaviour of T and activation products in the environment; assessment of design and safety documentation for ITER and EU alternative concepts; assessment of plant safety and availability for a fusion reactor.
- The fusion technology programme includes research and development within: materials characterisation, T and activation products safety, waste management and disposal, development of plasma facing components, co-ordination of safety and environment tasks, and socio-economic research.

Staff Professionals: 58 my/y Support staff: 14 my/y
Yearly budget (expenditure 1999): about 8 MioEURO
Management structure: Head of Research Unit: Prof. M. LISAK, Chalmers University of Technology
The Natural Science Research Council (NFR) is the responsible Swedish funding authority.

Status: February 2000

ASSOCIATION EURATOM/ÖAW - Österreichische Akademie der Wissenschaften

Contract Nr. : ERB 5004 CT 96 0020 001
Period : 15/11/1996 - 31/12/2000

Research Unit:
The Austrian Research Unit consists of research groups at:
ÖAW-TU (Technische Universität), ÖAW-U (Universität), Wien
ÖAW-U (Universität) Innsbruck
ÖAW-ÖFZ (Österreischisches Forschungszentrum) Seibersdorf
ÖAW-TU (Technische Universität) Graz
ÖAW-AI (Atominstitut der Österreichischen Universitäten) Wien
ÖAW-Böhler Edelstahl, Kapfenberg (1.1.98-31.12.98)
ÖAW-ARGE Wärmetechnik, Graz (3.7.97-31.12.98)
ÖAW-Plansee, Reutte (as of 1.1.99)
Erich-Schmid Institut für Materialwissenschaft (as of 1.1.99)

Present scientific and technical programme

1. Physics programme:
Edge Plasma Theory (U. Innsbruck), Edge Plasma Diagnostics and Modelling (TU Wien), Transport and Dynamics of Ignited Plasmas (ÖFZ Seibersdorf), Charged Fusion Product Confinement in JET (from 1/1/2000), Electrostatic Plasma Turbulence – Test and Development of Langmuir Probes (Univ. Innsbruck), Electron Impact Ionization and Surface Induced Reactions of Edge Plasma Constituents (Univ. Innsbruck), Studies of Cyclotron Heating and Current Drive (TU Graz), Basic Transport Theory of Fusion Plasmas via a Multiple Timescale Approach (Univ. Innsbruck)

2. Underlying Technology
Evaluation of Neutron Cross Sections for Fusion-Relevant Materials (Univ. Wien), Improvement of Materials and Testing Methods for Superconducting Magnet Components in a Radiation Environment (Atominstitut), Neutron Inspection of Fusion Relevant Materials - Influence of Hydrogen (Univ. Wien), Neutron Inspection of Fusion Relevant Materials - Neutron Micro-Radiography (Atominstitut), Advanced Characterisation Techniques for Ferroelectric Thin Films (Atominstitut) (from 1/1/2000)

3. Technology Tasks:
Next step: Electrical Properties of Magnet Insulation Materials in the Irradiated State (Atominstitut), Radiation Effects on Fusion Magnet Materials (Atominstitut), Materials for Superconducting Fusion Magnets (TU Wien), Thermal Desorption Measurements on First Wall Protection Materials (TU Wien), commitment for 1999, Investigation of D/T retention in N-irradiated PFC materials (Be, C, W) (TU Wien), Alternative Bolometers based on Ferroelectric Thin Films (Atominstitut).
Long term: SiC-SiC ceramic composites (Atominstitut), Chromium alloy development (Plansee and Erich-Schmid Institut), or Technology to start in 2000:

4. Socio-Economic Research on Fusion (SERF) :
Projects completed in 1999: Democracy and Autonomy in a Complex, Centralising Technology (Univ. Wien), Fusion Power as an Additional Vector in the WEC/IIASA World Scenario (ARGE Wärmetechnik).
Project started in 1999: Trust and Licensing Procedures for large Fusion Devices (Univ. Wien)

Achievements during the last 5 years

- Non-destructive inspection routines for actively cooled plasma-facing components (1997-1998)
- Remote handling – attachment of blanket modules to the back-plate (1997-1998)
- Mass spectrometry of hydrogen and helium (1997-1998)
- Reduced-activation ferritic / martensitic steel development (1998)

- Development of fusion edge plasma codes and diagnostics
- Fusion edge plasma relevant A&M data
- "Stochastic Mapping Technique" for plasma electron distribution functions
- Evaluation of neutron cross sections of fusion relevant materials
- Characterisation of superconducting materials for fusion experiments
- Influence of neutron irradiation on superconductors and superconducting magnet insulation
- Alternative structural materials for fusion reactors (SiC-SiC, Cr alloys
- Socio-economic research on fusion….

Staff : (1999) Professionals: 53.0 my
Support staff: 7.0 my
Overall expenditure : about 4.2 Mio EURO for 1999
Management Structure Head of Research Unit : H.-P. WINTER, TU Wien

Status: February 2000

ASSOCIATION EURATOM/RISØ - Forskningscenter RISØ

Contract Nr. : 348-89-1 FUA (DK)ERB 5000 CT 910002
Period : 01/01/1988 - 31/12/2000

Research Unit : Risø National Laboratory
Fusion Research Unit
OFD - 128
P.O. Box 49
DK-4000 Roskilde

History of Association/Laboratory
First contract of Association established in 1973

Present scientific and technical programme
- Theoretical and computational studies of electrostatic turbulence and turbulent transport in magnetised fusion plasmas.
- Research and development of new laser-based diagnostics with increased spatial resolution for studies of turbulent density fluctuations in fusion plasmas.
- Theoretical and experimental studies of plasma turbulence in Stellarators (in collaboration with IPP Garching).
- Effects of irradiation on physical and mechanical properties of materials such as copper- and iron-based alloys relevant to the Next Step and the Long-Term Technology programmes.

Achievements during the last 5 years
- Successful installation and operation on W7-AS of two-point laser diagnostic for measurements of turbulent density fluctuations
- Development of a fully three-dimensional, time-dependent numerical code based on first-principle physics for investigations of drift wave turbulence in the edge region plasma
- New theoretical model based on Turbulent EquiPartition (TEP) for description of inward transport, transport barriers and intermittency
- A new theory for void swelling and its verification by numerical calculations and specifically designed experiments
- A new model for radiation hardening and plastic instability (embrittlement)
- Identification of copper alloys for their application in the first wall and divertor of ITER-like machine

Staff
Professionals : 11.5 man-years
Support staff : 8.5 man-years

Yearly budget (expenditure 1998): about 3.0 MioEURO

Management structure
Head of Research Unit : J.P. LYNOV

Status: February 2000

ASSOCIATION EURATOM/TEKES - National Technology Agency, Finland

Contract Nr.: ERB 5000 CT 95 0000
Period: 13/03/1995 - 31/12/2001

Research Unit: The Finnish Research Unit consists of research groups at:
VTT Chemical Technology, VTT Manufacturing Technology, VTT Energy, VTT Automation, VTT Electronics, Helsinki University of Technology, Tampere University of Technology and University of Helsinki

History of Association/Laboratory
The Finnish Association was set up in March 1995, with the National Technology Agency Finland (TEKES). A programme has been established, which is carried out at various research institutes in the Technical Research Centre Finland (VTT), Universities and industry.

Present scientific and technical programme
The Association concentrates on work in a small number of areas, where existing expertise shall be developed in order to establish centres of excellence.

Fusion physics and plasma engineering are carried out at VTT Chemical Technology and at Helsinki University of Technology. The emphasis of this work is in theoretical and computational studies on rf-heating and current drive which are carried out in close collaboration with European tokamak experiments.

The work in fusion technology includes: research on **fusion reactor materials:** First wall materials and joining techniques at VTT Manufacturing Technology, fusion neutronics at VTT Energy and deuterium-tritium mobility and inventory in plasma facing materials at University of Helsinki and VTT Chemical Technology.

A second domain of fusion technology consists in **remote handling and viewing systems**: In-vessel viewing systems (IVVS) at VTT Automation, VTT Electronics and at Helsinki University of Technology and the development of water hydraulics tools and manipulators for the Divertor Refurbishment Plant at Tampere University of Technology.

Achievements during the last 5 years
- Transport and heating modelling (ICRF+NBI+LHCD) for high performance experiments of JET.
- Development of the multi-purpose Monte Carlo particle following code ASCOT for heating and transport
- analysis in tokamaks: L-H transition model based on ASCOT transport simulations in ASDEX Upgrade and JET.
- Particle-in-Cell (PIC) simulations of parasitic absorption and resulting heat loads in the LH-grill of Tore Supra.
- Design of the ICRH vacuum transmission line dielectric window including manufacturing tests.
- Molecular dynamics simulations showing the suppression of carbon erosion by hydrogen shielding.

- Concentration independent and dependent diffusion of hydrogen isotopes in diamond like carbon films
- Irradiation testing of high strength Cu-alloys showing the superiority of CuCrZr alloy at operating temperatures.
- Development Cu/SS joining techniques (explosion welding, HIP) and characterisation methods for Cu/SS joints.
- Neutronics calculations and nuclear analysis of ITER heating systems and equatorial heating ports.
- Development of water hydraulic tools and manipulators for ITER Divertor Refurbishment Platform.
- Design and feasibility demonstration of the ITER In-Vessel Viewing System based on linear array of optical fibres.

Staff : Professional : 30 my/y
Support staff: 2 my/y

Yearly budget : about 3 MioEURO

Collaboration with other institutions
JET, EFDA CSU-Garching, IPP, CEA, ENEA, FZK, Risø, CRPP Lausanne

Management Structure
Head of Research Unit: S. KARTTUNEN
VTT Chemical Technology / Industrial Physics
P.O. Box 1404, FIN-02044 VTT, Finland
Email: seppo.karttunen@vtt.fi

Status: February 2000

ASSOCIATION EURATOM/UKAEA - United Kingdom Atomic Energy Authority

Contract Nr.: 340-88-1 FUA (UK) ERB 5000 CT 90018
Period: 01/01/88 – 31/12/2001
Research Unit: UKAEA Fusion, Culham Science Centre, Abingdon, Oxon OX14 3DB, UK

History of Association/Laboratory

The Association dates from January 1st, 1973 when the UK joined the Community but co-operation between the UK Programme and European Programmes had existed for some time prior to the formal participation in Euratom activities. In the UK, work on plasma physics and controlled thermonuclear research was originally based at Harwell and Aldermaston. This work was transferred to the newly established Culham Laboratory in 1960-63. During 1973-76, Culham acted as host to the JET (Joint European Torus) Design Team and was then the host site for the JET Project from 1977. Since 1 January 2000, the Association has been responsible for the safety, maintenance and operation of the JET facilities (via the JET Operation Contract) to enable a collective European programme of experiments under the auspices of the JET Implementing Agreement. It also provides host support to the EFDA Close Support Unit at Culham. The UK Association's programme is presently centred on two experiments COMPASS (COMPact ASSembly), a small "ITER-like" tokamak which came into operation in 1989, and the MAST (Mega Amp Spherical Tokamak) facility, which commenced tokamak operation in 1999. MAST follows the successful START (Small Tight Aspect Ratio Tokamak) experiment, the world's first hot plasma spherical tokamak experiment, which operated 1990-1998.

Present Scientific and Technical Programme

The programme concentrates on the tokamak line and, in particular, support for JET and ITER. The programme also addresses concept improvements, notably the tight aspect ratio (spherical) tokamak, as well as the theory of fusion plasmas, safety, environmental and socio-economic assessments of fusion power, and the properties of materials in a fusion environment. The programme has an initiative to help industry benefit from fusion research, including identifying spin-offs into other markets, includes links to related areas of basic science, has an annual Plasma Physics Summer School, and participates in the European Programme's keep-in-touch work on inertial fusion via research at the Rutherford-Appleton Laboratory.

Achievements during the last 5 years - the Association has:

- Led experiments on COMPASS-D and JET which defined the requirements for the ITER error field correction coils
- Identified (on COMPASS-D) neo-classical tearing modes (NTMs), the main pressure-limiting phenomenon for ITER, and then showed how RF waves could be used to stabilise NTMs. Led related experiments on JET on scaling with plasma shape and current. Originated and developed the most successful theory of NTMs.
- Demonstrated, using RF heating and current drive, *sustained* high pressure tokamak plasmas (COMPASS-D)
- Improved understanding of enhanced confinement regimes and how they are accessed, through experiments on COMPASS-D and START, scaling comparisons with other devices, and model development via ITER expert groups

- Implemented the main JET current profile diagnostic (from the US), essential for understanding advanced regimes
- Pioneered the new, compact spherical tokamak concept through experiments on START and related theory ⇒ improved understanding of tokamak scalings, plus demonstration of world record normalised pressure in a tokamak system (β ~ 40%), with resilience to disruptions and good confinement (including H-modes) and exhaust properties
- First experiments on the new MAST spherical tokamak facility, with Neutral Beam and RF heating
- Demonstrated that activation codes used for modelling ITER and conceptual power plants agree with (a) measurements of activation by D-T neutrons on JET, and (b) measurements from Japan's Fusion Neutron Source
- Helped develop ITER systems: heating & current drive, safety, neutronics, error field correction, etc.
- Took leading roles in safety and environmental assessments of fusion power (SEAFP and subsequent studies), and performed analyses which helped show how the potential safety and environmental benefits of fusion can be realised.
- Conducted integrated physics/engineering studies of conceptual power plants (conventional and spherical tokamaks), using system codes to identify key drivers for the most economic systems (advanced physics, good availability, etc.)
- Highlighted the key issue for fusion systems of tritium retention and its waste implications
- Organised 1998 Royal Society meeting on fusion, bringing together magnetic and inertial fusion communities plus key members of the UK academic community
- Co-ordinated the Associations' exhibition at the European Parliament, Nov/Dec 1999
- Launched initiative to help industry benefit from fusion research: contract opportunities and technology transfer
- Collaborated with many Associations, universities and other institutes, including an initiative to help maximise value of fusion research to other areas of science

Staff
Professionals: 240
Support staff: 61
Plus many contractors and students

Expenditure in 1998
21.4 MioEuro.
The UK share of the funding is from the Department of Trade and Industry.

Management Structure

Head of Research Unit:	D C Robinson (Director, UKAEA Culham);
Assistant Director:	F Briscoe

Status: February 2000

JOINT EUROPEAN TORUS (JET)

Research Unit : JET Joint Undertaking
Abingdon, Oxfordshire
GB-OX14 3EA

History
From 30 May 1978 until the end of 1999 the JET facilities were operated as a Joint Undertaking of the European Community. Following the termination of the Joint Undertaking, the UKAEA was awarded the contract to operate the facilities. The EURATOM Associations, within the framework of the European Fusion Development Agreement (EFDA) are now responsible for the scientific and technical programme.

Scientific and technical programme of the Joint Undertaking
The original mandate of the JET Joint Undertaking was to: "construct, operate and exploit as part of the Euratom fusion programme and for the benefit of its participants, a large torus facility of Tokamak-type and its auxiliary facilities in order to extend the parameter range applicable to controlled thermonuclear fusion experiments up to conditions close to those needed in a thermonuclear reactor". For this aim, a plasma approaching reactor conditions was created and studied. The subsequent extension of the Project to 1996 and then to 1999 allowed additional objectives to be set: "to establish the effective control of impurities in conditions close to the Next-Step and to provide further data of relevance to ITER, especially for the ITER-EDA, before entering into a final phase of Deuterium-Tritium operation".

There were four principal areas of work: the study of scaling of plasma behaviour as parameters approach the reactor range; the study of plasma-wall interaction in these conditions; the study of plasma heating; the study of alpha-particle production, confinement and consequent plasma heating. A major focus was the study of divertor physics and the technology of divertors in order to provide key information for design of a Next Step fusion device and ultimate commercial systems. JET also developed two of the new technologies that will be required in fusion power stations: the use of tritium and remote maintenance and repair techniques.

Achievements of the Joint Undertaking in the 5 years to the end of 1999

- The JET deuterium-tritium experiments produced record fusion power of more than >16 MW for about one second, corresponding to Q=0.65.
- In quasi-steady state conditions (limited by external technical constraints) a record fusion energy of 22 MJ (from a power of 4-5 MW for about 4 seconds) was generated.
- For the first time on a fusion device, and under the constraints imposed by a radioactive environment, two of the technologies essential to the Next Step and a future reactor were demonstrated: remote handling of complex in-vessel components and closed-cycle tritium handling.
- Clear evidence of alpha particle heating was found in JET D-T plasmas, in line with theoretical predictions.
- The additional heating power threshold for access to the H-mode was shown to be 25% lower in D-T and tritium plasmas than in pure deuterium.
- Divertor concepts were further developed, with the original Mark I divertor being replaced by the Mark II, and finally the Mark IIGB ("gas box") configuration favoured for the next generation of fusion devices. A broad programme of divertor assessment in high performance plasmas was carried out, and experiments with the Mark IIGB divertor showed that helium exhaust in ELMy H-modes is compatible with reactor requirements.
- Scaling studies, in which dimensionless plasma quantities were kept identical gave, in conjunction with data from other experiments, improved confidence in the performance predictions for ITER.
- Operation in the "optimised shear" regime with high confinement due to the presence of an internal transport barrier (ITB) was demonstrated, and progress was made towards extending this mode of operation into steady-state.
- The factors affecting the onset and severity of neo-classical tearing modes (NTMs) have been investigated and the effect on plasma performance below q=3 has been demonstrated.
- Plasma regimes with high density, high radiated power fraction and small ELMs, which are key elements of the current ITER design, have been found to be associated with high ELM frequency, low pedestal pressure and correspondingly reduced global energy confinement time.

Status: end 1999

ANNEX 2: International Fusion Agreements

JET JOINT UNDERTAKING
JET was established in 1978, as a Commission Joint Undertaking (a novel solution to combine Community and Member States funds) and up until the end of 1999 has been managed by the JET Council, comprising representatives of the Commission and the organisations from Member States.

NEXT EUROPEAN TORUS (NET)
The NET Agreement (1983-1998) provided the framework for European collaboration in research and development in support of the Next European Torus and then in 1992 facilitated European participation in the International Thermonuclear Experimental Reactor (ITER) Project.

INTERNATIONAL THERMONUCLEAR EXPERIMENTAL REACTOR (ITER)
Quadripartite agreement between Europe (including Canada), the USA, the Russian Federation and Japan under the auspices of the IAEA for the development of the conceptual design (1988-1990) and subsequently the engineering design (ITER-EDA, 1992-2001) of the 'Next Step'. The US withdrew from ITER in 1999.

EUROPEAN FUSION DEVELOPMENT AGREEMENT (EFDA)
At the beginning of 1999, the new European Fusion Development Agreement (EFDA) came into force; it has been signed by the Commission and all the National research institutes and provides a framework for the continuity of European activities in the field of thermonuclear fusion. In particular, the EFDA Workplan now includes the technology work carried out by the National research institutes and by European industry, European contributions to international collaboration such as ITER and the exploitation of the JET facilities after 1999.

JET IMPLEMENTING AGREEMENT (JIA)
The JET Implementing Agreement (JIA), is between Euratom and the other parties of EFDA, and includes provisions relating both to the technical programme and the financing of the activities.

FIVE-YEAR ASSESSMENT OF THE SPECIFIC PROGRAMME: NUCLEAR ENERGY:
Nuclear Fission and Radiological Sciences

FINAL REPORT

L. Patarin (Chairman)

M Hayns (Rapporteur)

A. Salo

G Eggermont

P-E Ahlstrom

June 2000

1 Introduction

In accordance with Article 5 of both Decisions on the EC and EURATOM Fifth Framework Programme, the Commission is required to have an external assessment into the implementation and achievements of Community activities during the period 1995-1999 before submitting its proposals for a Sixth Framework Programme. This document represents the Final Report of the Board engaged in this task in the Specific Programme (SP) of Nuclear Energy, and in particular the Key Action 2 "Nuclear Fission " and the Generic Research in Radiological Sciences.

Nuclear Energy continues to contribute approximately one third of The European Unions electricity supply. As such it represents a very large investment, both in physical plant and human resources. Nuclear technology is demanding in terms of knowledge and expertise and the public rightly demands that the highest levels of safety and competence be maintained. The EU research programmes have had this as an ultimate goal since the original EURATOM Treaty was signed in 1957. Then, as now, energy from nuclear fission has been seen as a contributor to a balanced energy supply strategy, and as a potential building block of a sustainable energy future. To fulfil this function, the demonstration of exceptionally high levels of safety for all aspects of the fuel cycle is paramount, as is public acceptability. Also included in this specific programme are projects from a wide ranging area of research in radiological protection aimed at optimising protection and reducing exposure of the public and workers to radiation from all sources, from naturally occurring radiation, to the medical and industrial uses of radiation. Underpinning it all is a programme of generic Research in Radiological Sciences, which investigates the fundamental actions of radiation on tissue. The contributions of this work over many years to the health and quality of life of the European Union's population is well recognised.

The five-year period covered by this report includes the completion and appraisal of the Third Framework Programme (FP3) (1990-94), the completion and partial appraisal of the Fourth Framework Programme (FP4) (1994-1998) and the initiation of the Fifth Framework programme (FP5) (1998-2002). The reshaping of the Framework Programmes in the early 1990's is described in the previous five years assessment. Eventhough this report overlaps in time to some extent with that report we do not repeat the steps that were reported there. However, the process continues and there was a quite considerable change in structure of FP5 from that of FP4. This was not limited to the specific programme, of course, but perhaps because of its long history and the recent changes between FP3 and FP4, lead to a good deal of confusion in the technical community as to the required emphasis and focus. Parts of the specific programme have been likened to a shopping list, not a strategic research plan.

The terms of reference for this review (Annex 1) require that it should be done in the structure of FP5. This is not easy, as there are significant differences between FP4 and FP5 in its basic structure. To facilitate our task we have used the "translation table" shown in Annex 2. If the structure of the FP has changed, the basic objectives have not. The table shown in Annex 3 summarises how the overall objectives have evolved with time.

FP5 comprises Key Action 2, Nuclear Fission with four sub-headings, and one Generic Research programme in Radiological Sciences. In addition the programme has an action on Support for Research Infrastructures. The aims of the different parts are summarised in the table in Annex 4.

Data for the number of projects funded, the number of partners (and the number of different member states represented) in each project, the size of the projects and the ratio of shared cost to concerted actions are all available. The trend over this period has been for a decrease in overall funding and some considerable internal re-focussing of research. This is summarised in Annex 5. We will comment on specific aspects below, but it is clear that in operational safety there has been a move away from severe accident research, which in some areas is reaching maturity, to issues related to materials ageing, plant life management and human factors. However, the inclusion in the area "safety of the fuel cycle" of Partitioning and Transmutation is something we have doubts about and discuss more fully below. The necessity to generate a separate "Generic Research" area caused much confusion in the radiation protection community and has lead to a rather unsatisfactory situation mid way through FP5.

Method of working: the Board received a large number of reports covering all aspects of the programme. A summary list is given in Annex 6. In addition interviews and visits were undertaken to give an opportunity for the Board to gather first hand views from those concerned in implementing the programme as well as with DG Research staff. More than 100 people were interviewed; their names and affiliations are given in Annex 7. Finally, the Board members and their backgrounds are given in Annex 8.

The Board wishes to express its particular thanks to members of DG Research staff who have made time available for interviews and have been very supportive in this task

2 Assessment of Implementation.

2.1 ASSESSING EFFICIENCY

2.1.1 THE ROLE OF ADVISORY GROUPS

The Nuclear Energy R&D Programme has advisory committees that reflect its EURATOM Treaty basis. The Scientific and Technical Committee (STC) has held the principal strategic advisory role for many years, with the Programme Committee[4] (CCE) also having been long established with an overview of the way in which the programme is managed. In addition for FP5, there is a new External Advisory Group (EAG), which has a mandate to comment on the content and programme planning of the FP5. We believe that there might be a role for all of these groups. However, there seems to be insufficient co-ordination between their activities and there needs to be a more effective and efficient management of the considerable expertise and knowledge available through them. Cross membership of the STC and EAG helps to some extent, but a more pro-active use of the groups would help. The technical committees (STC and EAG) in particular are made up of very experienced people who give their time voluntarily. It would be valuable to have an evaluation of the mandates and interfaces of these advisory groups. The STC continues to play an important role, especially in strategic matters and taking long term views. It has remained flexible to the changing needs of the Commission and the end users. A key element in the success of any of these groups is the information available to members. The Commission can do only so much and it is important that Members have appropriate networks/contacts nationally and internationally in order to contribute effectively. In addition, it is most important that they are brought into the process early enough to be useful. As a case in point, the timing of the preparation for FP5 meant that the new EAG did not get off to a good start.

[4] In the case of the EURATOM programme, this is the Consultative Committee for EURATOM (Fission) (CCE Fission).

2.1.2 PROGRAMME MANAGEMENT.

In general terms we believe that the programme objectives have been pursued in a cost-effective manner. This, of course, is subject to a number of caveats and criticisms. The "transparency" of the management of the programme has been improved and the staff of DG Research have made significant contributions to its success. The process of calling for tenders and evaluating them remains very bureaucratic and heavy handed. Improvements have been made, e.g. by the extensive use of electronic means of communication. Nevertheless it remains a daunting task for a research manager to write a proposal, gather together an EU wide consortium and submit it for evaluation. Added to that is the very long time between submittal and acceptance. The annual monitoring reports have made suggestions as to how this process may be speeded up (e.g. by seeking input from other DG's in parallel with the proposal progress rather than in series) and we support those suggestions. Long delays can also add to problems of continuity for some players. However, as long as the demands for scientific excellence, transparency and auditability remain, it is inevitable that proper review and safeguards procedures must be in place and these will take time and effort. It is true that the evaluation process has been improved, but it still remains difficult to balance experience, independence and availability of suitably qualified people in what is a relatively small pool of experts in Europe.

Once projects have been awarded, there is a strong case for giving more authority to the project co-ordinators. They should be allowed to manage flexibly and to ensure that objectives and targets are met in the most efficient way; this means that changes must be possible once a project is underway. This should be accompanied by more assistance from Commission staff on strategic and networking matters. It has to be remembered that research is not always going to give foreseeable results and good researchers need to be able to make adjustments as knowledge is gained.

The projects in the specific programme of Key Action 2 and Generic Research in Radiological Sciences have historically had good, highly motivated scientific officers in the Commission. This has lead to the situation where much of the added value of the work comes from these few individuals. In recent times the number of personnel has been decreasing. This throws more emphasis on the need for a change in the nature of the programme management. In the area of radiation protection in particular recent sharp falls in staffing levels means that the number of personnel is now under the minimum critical mass. This is a very difficult position since during the past 10 years or so, the EU programmes have become world leaders in many aspects of basic radiological research. For example, the ICRP is now relying more on European research centres than those of the USA. Now is the time to consolidate that position, not withdraw from it.

The major divisions between the FP programme management and the JCR's have been a problem for a long time. Establishing appropriate connections is difficult, and depends largely on the management culture, and the motivation of individuals. We are assured that problems are recognised and are being tackled by the DG Research staff responsible. This effort needs strong support from higher management.

There have been many "structural" changes in the programme and this has led to some difficulties associated with the transitions between one FP to another. The most common complaint from project co-ordinators was the potential lack of continuity. In some cases (especially FP4-FP5) the delay in implementing the new programme meant that either work had to stop, or research bridging finance from the host Institute had to be found. For large national programmes, or Institutes with some degree of autonomy over their budgets this was not a big problem, but for smaller Institutes or privatised organisations it was intolerable. In addition, the change in programme structure for radiation protection from FP4 to FP5, i.e. the splitting between key action and Generic Research, lead to a transition

that was too obscure. This, and the reduction of resources, caused many problems for potential contracts and for DG Research staff.
Finally, in terms of efficiency, we attempted to judge the value of the outputs of the research in terms of the resources used. This is a notoriously difficult process even for far down stream research. In some areas of research, some quantification is possible; for example, the research done under the ETHOS project has given practical information on how a population could safely resume living in a contaminated area. Other examples might include the resolution of the in-vessel steam explosion issue so that such events can be safely ignored in accident management procedures and for future reactor designs. In many cases, the Commission funds represent only a small fraction of the total investment. Examples include the PHEBUS experiments and underground laboratories for waste disposal experiments. Nevertheless, these resources are valuable in allowing other Member States to participate and in disseminating important knowledge widely amongst the European technical community. The main conclusions on "value for money" are summarised as;

- The quality of scientific research was given priority in letting contracts and this has ensured good quality output as a result.
- The "value" of bringing researchers together from many Member States (and now from Applicant Countries too) is not quantifiable, but is universally judged to be an important and necessary contribution to European Harmonisation.
- For some technical areas research is now mature and the resources which have been used can be seen to have contributed directly to problem solving applications.

2.2 ASSESSING EFFECTIVENESS.

In attempting to judge effectiveness, the Board has followed the guidelines given to it in Annex 1. This means that there is some overlap with comments above under the heading of Efficiency.
In judging whether the activities funded were of high scientific and technical quality and relevant to the objectives, the Board gives its specific views in the individual work areas. In general terms, the work that was supported has been of a consistently high quality. This is reflected in the publication of numerous papers in professionally reviewed journals, and in the use of the outputs of the work by Regulatory Authorities, international bodies such as the ICRP, in underpinning EU Directives, and, of course by the industry.
There has been considerable EU added value[5] throughout these projects. Much of this arises from the multi-national approach through consortia drawn from different Member Sates to perform the research. There are a number of common problems that benefit from

[5] It is surprising to the Board that there is no generally agreed definition of "European Added Value". It is surprising because it is a central plank of the FP5, and all potential bidders for work are asked to identify where their proposal contributes to it. We understand that a study is underway at the moment, but will not be available before the deadline for submittal of this document. Therefore, for clarity we offer the following as "our working definition".
A Research project has European Added Value if it offers one or more of the following;

- Increases the availability of Research data and knowledge throughout the Union (and Applicant Countries).
- Addresses a problem that is common to several Member States.
- Engenders closer collaboration between Research Institutes and research workers in the Union.
- Generates scientific consensus on key issues for regulation and in publicly sensitive areas of scientific and industrial policy.
- Increases efficient use of resources for example
  - By allowing the Union to speak with one voice internationally.
  - By making expensive or unique facilities commonly available
  - By creating the necessary knowledge base.

a common solution, not least to ensure consistency of regulation and interpretation throughout the Union. Having an EU wide S&T consensus is also very important in sensitive areas such as the requirements to protect people from sources of radiation, both man made and natural or such as the management of radio-active waste.

This description of European added value also applies to the contribution of the specific programme to social objectives. The contribution is essentially derivative. That is it underpins other activities that are more directly involved. For example, in terms of employment, clearly an active industry requires stable and cheap energy supplies. In terms of quality of life and health, much of the programme in radiation protection is aimed directly at ensuring that people are both protected from harmful radiation and that benefits through medical applications are used effectively. Should there be a large nuclear accident, then the programme is also aimed at providing the common warning, protection and recovery procedures.

In terms of contributions to the harmonious and sustainable development of the Community, we would reiterate that public confidence is absolutely vital. The research programme has helped to engender that by improving the knowledge base, whilst recognising that societal interactions and values represent complex problems which also need attention. Sustainability, in terms of energy supplies, is a key issues and far too complex for a simple response here. However, it is clear that a safe and efficient nuclear fission programme for electricity production can offer decision-makers policy choices in the future if sustainability conditions are fulfilled.

The research integrates the spectrum of activities and disciplines that are needed for achieving the objectives of the Programme through a considerable degree of multi-disciplinary projects. There are many examples where scientific activities (measurement, computer modelling etc) are complimented by engineering solutions. For example in plant life management, it is necessary to provide a holistic approach to all the relevant materials and plant performance issues. It is also the case in aspects of land restoration that many multi-disciplinary facets must be taken into account, including socio-psychological issues.

3 Indications of Significant Achievements.

3.1 KEY ACTION 2: OPERATIONAL SAFETY OF EXISTING INSTALLATIONS.

This area of research is characterised by a significant shift from developing the necessary understanding of the phenomenology of severe accidents in FP3 and FP4 to the use of this information in accident management and to the increasingly important issues relating to plant and materials ageing in FP5. Many of the earlier results are being used directly in the new programme. In many areas the research has reached a point of "maturity[6]".

Under FP4 the work was focussed into clusters. These combined projects with similar technical interest for managing and reporting purposes. With the key actions structure of FP5 it is not so clear how such clusters may be formed. However, we believe that the added value found from most cluster activity in FP4 makes it worthwhile to follow this up in FP5, along with the additional networking envisaged.

[6] We use mature in a very loose meaning. It is recognised that there will always be further avenues of research even for the most highly developed areas, however, it is a matter of judgement and priority as to whether "fitness for purpose" has been reached. We use the term mature to mean the latter.

3.1.1 PLANT LIFE EXTENSION.

This area was not identified separately in FP4, although a number of projects were carried out in the "AGE" cluster. There was a very close collaboration with the established "AMES[7]" network that was managed by the JRC Petten. The increasing importance of this technical area is reflected in the weight given to it in FP5. As it concerns a mature Industry the Commission should maintain a balance between industrial and regulatory needs. Much of the background of the technical state of the art was provided by earlier projects. Significant achievements include;

- An overall appreciation of the many interacting aspects of materials performance through life which have to be drawn together to optimise plant life management.
- A comprehensive study of methods for assessing stress corrosion cracking in dissimilar welds has produced a series of recommendations on methods of testing.
- A major study (through concerted action) with the AMES network of non-destructive techniques for examining aged material has laid the groundwork for a next phase of qualification and industrial validation at the European level.
- A major state of the art report on modelling requirements to follow ageing processes has been produced.

3.1.2 SEVERE ACCIDENT MANAGEMENT.

The area of severe accident research has been receiving major international attention for more than 20 years. The achievements now emerging from the recent work have to be seen in the context of this large effort made by many countries. A number of significant achievements have been made under the general heading of severe accident research in the EU RTD programmes which have paved the way to the change in FP5 towards problem solving rather than basic research. The following gives a breakdown by the sub-topic areas of FP4.

IN and EX vessel corium phenomena. This work represents the culmination of many years of activity, nationally and multi-nationally to establish the physical behaviour of molten core material (corium) both in and ex vessel during the progress of a severe accident. Specific achievements include:

- It has been established that an in-vessel steam explosion (energetic molten-fuel coolant interaction) of sufficient size to threaten the reactor pressure vessel (RPV), especially the upper head can now be ruled out. This closes a long running, albeit low probability, initiation of major RPV failure.
- It has been shown that for core powers of up to 600MWe, and possibly up to 1000MWe, a molten core can be retained inside the RPV using external cooling. This provides important guidance for the design of new reactors and for Severe Accident Management (SAM) in many existing designs.
- A series of experiments has established that large amounts of corium are coolable when spread out in containment. This is important for design and SAM of larger reactor designs where RPV melt through cannot be ruled out. It also demonstrated that expensive ceramic materials were not necessary to achieve this.
- A smaller, but still important, example of problem solving in FP4 is the development of SAM procedures for preventing re-criticality events in Boiling Water Reactors (BWRs).

[7] The European Network on Ageing Materials Evaluation and Studies (AMES) is one of a number of networks in this area organised by the Institute for Advanced Studies (IAM) of the Joint Research Centre at Petten. The success of these networks has been instrumental in the focus on this mechanism for co-operation adopted for FP5.

Containment: This area has focused on the threats to containment from molten core material released from the RPV and from Deflagration or Detonation of Hydrogen gas produced as a result of oxidation of the Zircalloy and steel core components.

- Significant information is now available concerning the control of hydrogen, by ignition or recombination, sufficient for design and SAM solutions
- The threat to containment from Delayed Containment Heating[8] (DCH) has been shown to be very small.
- The leak rate through micro cracks in concrete has been shown to be very much reduced by water condensing in the cracks.

A significant new development has been the application of very sophisticated state of the art Computational Fluid Dynamics (CFD) codes to the complicated 3D problems in containment. The future development of these codes is important in this and many other areas of such work and represents a significant challenge to the "horizontal" co-ordination of EC activities.

Source Term: The many physical and chemical conditions and the number of different chemically active species involved has always made the fundamental calculation of the amounts of material which may be released in a severe accident, i.e. the "source term", very difficult. This is a very well co-ordinated programme with much bi-lateral as well as EU and other multi-lateral added value. Significant achievements include the demonstration that silver (from control rod material) has been shown to "fix" radioiodine and acts as a natural stabiliser, reducing the amount available for transport and release. Considerable progress has been made in producing models and codes that are detailed enough, and quick enough. Nevertheless there is still some way to go before this area could be considered to be mature. In this context, the planned future major tests in the PHEBUS[9] facility represent a continuing and important contribution. The contribution of the FPs to this project have been relatively small compared to the overall costs, but good added value has been obtained through collaborative activities both between EU Member States and particularly in the wider international scene. The series of tests has taken longer than originally planned, but this reflects the extreme experimental difficulties and the caution that must be exercised whenever experiments involving large amounts of radioactive material are undertaken. Progress towards the eventual goal of validating large fission product migration and release computer codes is being achieved. The Board noted that financial control of the EU funding has recently passed from JRC Ispra to DG Research. Eventhough there is no anticipated change to the funding for the FP contribution, this move will help bring the EU funded activities into the overall frame of the relevant activities under FP5, and possibly FP6.

Additional items. The mainstream research activity has been supplemented by a number of useful concerted actions. Examples include

- A survey of regulators to find their attitudes and needs from severe accident research.
- A benchmark for the use of engineering judgement, identifying the "rules" which should be applied.
- The generation of a database for Probabilistic Safety Assessments of severe accidents, including the availability of software platforms so that they can access the large amount of data now available.

Concerted actions such as this provide excellent value for money in giving overviews and strategic information on the mainstream research activities.

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[8] Delayed containment heating arises from the possible distribution of an aerosol made up from hot core debris directly into the atmosphere of the containment.

[9] PHEBUS is a large reactor based installation at Cadarache in France capable of melting fuel and monitoring the transport and deposition of fission products in scale model containment. It can be decontaminated between experiments and is in the middle of a series of tests investigating fission product migration and transport.

3.1.3 EVOLUTIONARY CONCEPTS.

This was not identified as a programme area in FP4 and the results relevant to it are summarised in the severe accident management section above, particularly the information relating to design data for ex-vessel core cooling. It also overlaps with the key action "safety and efficiency of future systems" which is discussed in section 4.3 below. In general terms we would say that future work in this area needs to be carefully considered as it is in danger of becoming very far "downstream" and therefore more appropriate to Industry funding either directly, or through safety research programmes deemed necessary by the regulatory authorities.

3.1.4 SUMMARY AND RECOMMENDATIONS.

Much has been achieved in giving a comprehensive underpinning knowledge for future problem solving applications. Data is available for the generation of SAM that will significantly improve safety margins. The results of earlier programmes have helped to crystallise the key phenomena so that future research will be better focused in risk significant areas. Although not a part of this assessment, the work of the JRCs also contributes in this technical area. Although this activity (so-called direct action) has its own review process, there is little evidence in the past that sufficient care has been taken to ensure consistency and a full exchange of information. There is evidence that with the change in structure following the introduction of FP5, and some changes in personnel this sorry state of affairs is changing. It is very important that any research performed by the JRCs is, and is seen to be, entirely consonant with that of the main FP.

Recommendations.

1. In order to capture the knowledge generated in the already completed research a continuing activity is required. This is to gather up data, results of experiments, models and codes and store them in databases in an intelligent and recoverable way for the future.
2. Some techniques currently being developed in the nuclear safety field have applications beyond their immediate purposes. An example mentioned above is that of CFD. It also includes topics such as the reliability of software based control systems and many aspects of human performance and man/machine interfaces. The horizontal links in FP5 could be put to good use in making these state of the art methods more widely available.
3. The general tightening of resources is strongly felt in this research area, where expensive major facilities are required. Some means for rationalising their availability in the future needs to be addressed and we will suggest that consideration be given to some combined EU actions in the future, perhaps through identified "centres of excellence".
4. The shift in emphasis towards plant life management and ageing issues is a prudent investment protection programme for European Industry and the needs of the Regulators.
5. The creation of networks as a means for increasing co-operation and dissemination of information is strongly encouraged. The area of plant life management already has a well-developed network system and this should be nurtured and encouraged rather than trying to set up new networks. Successful networks depend on the motivation of their members, any proposals for establishing networks should be preceded by "market research" which determines the need.
6. Although there has been a change in emphasis, some of the "traditional" areas of research need continuing development and support. Amongst these is thermohydraulics, where major computer code development remains a priority for underpinning future safety justifications.

7. The question of fission product migration and release is not closed and it is important that the key role of the PHEBUS experiments, and the supporting research aspects continue to receive support in the future.

3.2 KEY ACTION 2: SAFETY OF THE FUEL CYCLE.

The title of this section could be misleading as it only addresses some aspects of the fuel cycle and not only safety issues. The core of this part of the programme is nuclear waste management; concentrating mainly on the disposal of the important highly active and long lived waste. It also contains part of the decommissioning of nuclear installations and a long-term innovative development for the fuel cycle, that is P&T. Many operational safety and environmental issues related to the transport of nuclear materials, reprocessing and low and medium level waste management were not covered in FP4 and/or FP5 but were addressed mainly by national programmes. Fusion waste management and waste implications of new reactor and fuel concepts were also not covered here and should be addressed by the relevant programmes in a co-ordinated way. As can be seen in Annexes 2&5, the budget was halved for waste management in FP4, while P&T was transferred from the work area "Exploring Innovative Approaches and New Reactor Concepts" in FP4 to this area in FP5, with an increase in funding.

3.2.1 WASTE AND SPENT FUEL MANAGEMENT AND DISPOSAL

This part of the programme focuses on HLW disposal and has contributed to a successful international collaboration with a substantial input from new Member States. The budgetary constraints and new priorities made it difficult to maintain continuity in some key long-term projects and left little margin in FP5 for new projects and broader challenges in nuclear waste management. The new structure of FP5 makes it particularly difficult to follow the evolution of the sub-areas. The EC nuclear waste management research programme represents a relatively small contribution to research compared with national programmes. Because of the differing needs of these national programmes, it seems difficult to establish a clear strategy at the European level. An improved co-ordination with other DGs, more involvement of regulatory bodies and transdisciplinary studies could create progress towards the public acceptance objective.

Management Strategies. A project in FP3 on technical feasibility of retrievability in various host rocks continued as a concerted action in FP4. This yielded an inventory of views in 8 countries throughout different phases in disposal and helped the mutual understanding of different disciplines. A clear difference was illustrated between retrievability during operation and after closure. Implications were identified for repository design, technology, safety, monitoring and safeguard aspects and at the socio-political level. Retrievability is considered as an opportunity to gain public confidence but must not compromise safety. Further dedicated studies are needed to include retrievability scenarios in risk assessments and performance analysis and to better understand the identified limiting factors such as cost. A step by step reversible approach with sustained transdisciplinary R&D efforts integrating social and economic sciences in technology and risk assessment could offer perspectives for consensus and solve crucial problems of waste in future.

There were no proposals on waste management strategies from the first call for FP5. Discussions with project co-ordinators indicated that this was due to the call being too broad. Commission staff intend to rectify this in the second call through a re-focusing of the objectives.

During the five years covered by this assessment, there has been little work done on economic aspects of waste management strategy. This makes it difficult to assess competitivity aspects. Research projects in future could be more balanced by the inclusion of a wider participation of stakeholders, especially regulators. This could also improve the process of setting standards and criteria to make it more transparent and amenable to public debate.

Quality Checking of waste packages. A European network was initiated in 1992 to promote European collaboration in the quality checking of radioactive waste packages (Non-destructive methods, Destructive methods and QA/QC procedures). The Round Robin Test for non-destructive assays of radioactive waste packages was aimed at improving the accuracy of techniques across Europe. The results of the non-fissile tests were good, while the fissile tests were not so satisfactory. A system for the detection of non-uniform hot spot activity remains necessary.

A network forum on destructive methods is editing a guidebook. Inter-laboratory comparisons will be needed to validate the methodologies, which would then be accredited by member states.

The network working group on QA and QC procedures moved forward towards a draft report on low and medium level waste packages in order to increase confidence in the waste management systems and to harmonise procedures in the community. The global network can be considered as a success by creating valuable fora for exchange of information and has led to improved identification of R&D projects.

This is an important research area. If international QA/QC could be based on reliable measurement techniques, validated by international comparison and referring to internationally harmonised standards, controversy over international transport might be reduced. The EC reduced funding in FP5 due to budgetary constraints. Work continues under the (non-supported) European Network for QA/QC labs. For NDA of large volume packages from decommissioning a project was approved.

Repository Technology. The CLUSTER network[10] of underground research labs (URLs) with 24 contracting parties in FP4 can be considered as the core of this key area. The feasibility of repository concepts has been demonstrated with large field tests of the behaviour of components such as the engineered barriers. At the same time measuring the impact of the heat and radiation, with particular attention to backfilling and sealing in situ barrier studies under disposal conditions. The projects FEBEX (in collaboration with NAGRA (Grimsel granite), BAMBUS (Asse salt) and RESEAL (Mol clay)) were a successful synergy of near real scale in-situ tests, modelling, laboratory tests and fundamental studies with performance assessment (PA) feedback, whilst at the same time creating opportunities for confidence building. The high costs and long time scales of such experiments made them an appropriate focus for international co-operation. The increased common understanding of backfill behaviour of bentonite in most URL's is a European added value. In these experiments the thermo-hydro-mechanical (THM) processes in the near field are being monitored successfully with numerous sensors both in clay and crushed salt as backfill. The rather good correspondence between modelled and observed behaviour increased confidence and common understanding of backfill materials. The three projects were approved for continuation in FP5 with particular attention to the dismantling (semi real retrieval) and post mortem analysis after 9 years of heating in BAMBUS, which is considered as a final project on salt backfill behaviour. As handling of real waste underground was limited up to now and considering the problem of transferability of results obtained, a clear need for testing of components under real disposal conditions arose.

[10] Club of Underground Storage, Testing and Research facilities

Future activities in URLs have to integrate all the successive actions to be undertaken in repository development at a specific site, such as the Prototype Repository project at Äspö in Sweden, approved for FP5. The need for better dissemination of knowledge could be satisfied in FP5 by the thematic network CROP, a proposal selected for the research infrastructure area, to constitute a forum for pooling and assessing experiences from various URL's.

Performance assessment of repository systems. PA is a very complex activity covering a large set of disciplines and this means that there are many uncertainties that have to be accounted for. The underground site studies have offered unique opportunities to refine PA tools through successful international collaboration and scientific understanding. PA approaches and tools have been further developed during the last 5 years.

The SPA-project in FP4 covered the elements needed to come to a total system analysis of spent fuel disposal in various host rock formations (clay, crystalline rocks and salt formations). Progress was made with regard to the various source term models adopted by the participants, engineered barrier behaviour, the possible effects of an excavation damaged zone, scenario and biosphere definition and deterministic and probabilistic calculation methods. The importance of optimal selection of engineered barriers was illustrated.

A new method for global sensitivity analysis and a conceptual framework to account for all sources of uncertainty in simulation problems of complex systems was developed through the Gesamac project. An important message from the study is that the PA of complex systems needs to take into account scenario, structure, parametric and predictive uncertainties, but that scenario uncertainties dominate.

The geoprospective studies regarding the evolution of earlier climate to predict future hydrogeology was succesfully coordinated. It yielded important feedback for PA by gaining insight in uncertainties over 10^4- 10^5year periods, through changes in hydrogeology effected by climatic changes.

Major achievements were realised linking laboratory work, field experiments and modelling. This exposed more clearly remaining deficiencies in knowledge and challenges for strategies. These include; does P&T make sense from the point of view of waste management? How well are the varieties of potential source terms defined? How well do we have to define the biosphere? Natural analogues, closer integration of laboratory work, in situ tests, modelling of a real site and basic studies in migration in open geosphere systems will help to clarify some of these issues. Selected proposals in FP5 include future climate change simulation and the SPIN project which aims to identify, test and evaluate safety indicators such as biosphere releases of radionuclides, looking for less abstract indicators for robustness than potential small doses.

Long term behaviour of repository systems. This proactive program on basic phenomena focuses on natural analogues, migration and a thermodynamic database for environmental monitoring (JETDEM CA). Natural analogue studies were very successful. These studies covered a broad spectrum of important phenomena. The project at Palmottu (Finland), amongst other things, focused on hydrogeological behaviour characterising a (post) -glacial period. Results will help to estimate future behaviour of geology and to update future climate scenarios and their potential effect on technical barriers under changing hydrogeological conditions.

Important studies on the interaction between waste forms, container and repository materials were continued. In the CORALUS case, experiments in FP4&5 analyse in situ corrosion of active glass samples in clay, through migration profiles of leached radionuclides. Real exposure conditions of high dose and temperature will be applied on three interacting materials such as bentonite. International laboratory collaboration was successful and the local safety authorities accepted the design.

Another subject concerns better knowledge of the spent fuel source term, which is more complex than uranium dioxide in its near field interactions. The spent fuel characteristics are affected by the trend to high burn-up in reactors. It was surprising, considering the potential impact on long-term safety, that one of the important projects has not yet been included in FP5.

The role of a number of key issues in the radionuclide transport and retardation processes deserves further investigations. The characterisation and modelling of flow and transport through fractured rock is not fully understood. Clear progress was made on gas formation. Projects were grouped in the cluster PEGASUS on gas generation and transport through clay, fractured rock and salt. Gas research should be continued for particular waste forms such as containing organic fractions.

Important migration issues have been successfully coordinated by the EC at world level since 1983 with MIRAGE, covering 80 multinational and interdisciplinary research projects. This action was continued more specifically on the influence of colloids and humic substances in FP4. The HUMICS project in FP4 has indicated potential consequences for actinide transport assessment. Specifically, in the case of environmental release to the aquifer from a geological barrier, humic colloid mediated actinide transport could lead to an unhindered transport of part of the actinide ions. The project on the influence of humic substances under natural aquatic conditions was considered too ambitious and not approved in FP5.

TRANCOM, a success but not an end-point in FP4, improved the understanding of the role of the organic matter for radionuclide transport in a reducing clay environment.

Aquatic Chemistry and Thermodynamics (ACTAF) could provide new experimental data in FP5 about the behaviour of actinides and fission products in natural aquatic systems that will help to close gaps in the thermodynamic database.

BORIS (financed by DG Environment) addresses new and innovative aspects of how to assess migration and retention behaviour in two Russian liquid waste injection sites.

The last three projects will contribute to the assessment of the function of the geological barrier.

Public Attitudes and involvement. Little attention has been given up to now at EC level to public attitudes and involvement. There is one project and a concerted action in FP5 concerning the evaluation of transparency in decision making, but there are no activities such as consensus conferences or public discussions of safety criteria. There is a need to incorporate different aspects through work packages integrated into projects, and especially to involve social sciences.

Recommendations.

1. To account for uncertainties, to be able to consolidate scientific assessment, and to gain the confidence of the public, continued research at an international level with sufficient resources is needed in radioactive waste management, including basic studies
2. Research should also be supported to maintain the advanced knowledge, skills and research capacity in nuclear waste management, irrespective of nuclear energy options taken.
3. The implementation of a repository surveillance strategy is suggested as a concerted action for extending the retrievability action.
4. More harmonisation is needed of waste characterisation activities for some types of waste packages The suitability of various available techniques for waste package quality checking should be demonstrated.
5. Safeguarding and monitoring of repository sites with attention to long term operationally sustainable monitoring instrumentation is an important issue for the future and one where co-ordination with the JRC could increase.

6. As all nuclear waste is mixed, chemotoxic aspects should be integrated in a general way thereby giving rise to potential horizontal FP connections
7. Because of the continuing interest in the influence of microbiological activity, it is suggested that the Commission consider setting up a network in this area.

3.2.2 PARTITIONING AND TRANSMUTATION (P&T)

The aim of Partitioning and Transmutation is to separate long lived wastes and transmute them into shorter lived species so as to reduce long term radio-active waste disposal problems. Interest has been renewed during the 1990's in systems to achieve this driven by, for example, the Japanese Omega project started in the late 1980's, the new French law on nuclear waste research in 1991 and the developments in accelerator technology during the 1980's. The motivation of the proponents of P&T has been strengthened by the delays in siting and construction of repositories for spent fuel and/or high level waste. This is reflected in the increase of funding over FP3, 4 and 5. I.e. 4.8-5.8-17.3 MEUR[11] respectively. Such an increase is in line with the recommendations of the previous five years assessment Board. Recent studies in Europe and the USA have shown that the very optimistic claims made by some proponents of P&T in the early 1990's were not justified. The development of a P&T system will take a long time, many decades, and furthermore, will have to be operated for very much longer, perhaps more than a century, in order to substantially reduce the amount of transuranic elements produced by current power reactors (or alternatively reach an equilibrium level of actinides in any new fuel cycle). There are also concerns over the potential radiological impact of P&T systems as these systems involve the active control and destruction of the long lived nuclear wastes and will require the complex recycling of large amounts of very radioactive material. The risks from such an active and complex system have to be compared to the relatively robust system for geological disposal. In addition to the projects supported by DG Research under the FP, a number of projects are funded by the EU (and also jointly by partners) within the ISTC and ISTU[12]. These projects have close informal contacts with FP funded projects.

National programmes in member states dominate the projects within this part of the programme. There is a clear dichotomy of views, some experts question the increase in funding in FP5, whilst others believe that the resources made available are too limited. There is no coherent set of national programmes on P&T in the EU, reflecting mainly the lack of a coherent fuel cycle policy between Member States. The trend away from reprocessing towards a once through cycle is another reason why P&T is less favoured. Despite this there is a strong will to participate in European collaboration. Even organisations fully committed to the once through fuel cycle find it prudent to support limited efforts on research in P&T in order to be able to evaluate the concept and compare it to direct disposal. Likewise, organisations committed to recycling wish to investigate any possible complementary technologies to present reprocessing and recycling systems. There are also pressures brought about by political lobbying for the exploitation of the P&T concept. All of these issues have made it possible to create the current will for a co-operative programme in some of the key research areas in P&T.

This is an area where international co-operation has become widespread, with many partners being involved. This has many advantages, but it has to be recognised that it is also considerably increasing the burden of project co-ordinators.

Work done under the FP4 has yielded some very promising result. In particular, progress has been made in the separation of tri-valent actinides (americium and curium) from

[11] Note that this is the amount actually awarded in the first call of FP5. The total available is approximately 26 MEUR.

[12] The Institute for Science and Technology (ISTC) was set up in Moscow specifically to help Russian weapons scientists. The ISTU is the corresponding institute for Ukraine.

lanthanides. The results suggest that it may be possible to develop a process with a single cycle allowing direct extraction of the minor actinides from the very acid high level liquid waste from reprocessing. This research is being followed up in FP5.
The projects concerning transmutation in FP5 have a clear tendency towards ADS. However, there have been no projects selected on design and evaluation of transmutation systems, nor on the important topic of the safety features of such systems. Additionally, some research to provide the basis for comparing the radiological risks from alternative P&T is needed. The staff of DG Research is aware of this and this is reflected in the priorities for the second call for proposals.
Although the present focus of the P&T proponents is for a European facility based on an accelerator driven system (ADS), it is not clear to us that this route will be easier than the liquid metal cooled (LMR) fast reactors which were persued so vigorously during the period 1960 - 1985. The clear message from that experience is for caution and a thorough basic development before entering into any large-scale demonstration programme. This should be the aim of near term research and, in that context the FP5 programme objectives and the EU projects awarded in P&T seem reasonably well chosen.

Recommendations.

1. In FP5 P&T is included in the category "Safety of the Fuel Cycle". Recent studies have clearly shown that any successful development will need a long time before any industrial application is possible. Furthermore P&T will not eliminate the need for deep repositories; it will only change the properties of the waste that has to be disposed of. Finally, the transmutation of substantial parts of the waste for the current nuclear power programme would require a very long time indeed. It would therefore seem logical to us that further research on P&T systems should be evaluated and grouped in the category "Safety and Efficiency of Future Systems".
2. Projects concerning conceptual design and evaluation (including safety properties and waste issues taken in the broadest sense) of ADS systems should be given priority in future calls for proposals.
3. The concept of P&T is under development and its technical realisation undergoes frequent changes. Strategic studies of the complex system(s) for P&T need to be done and to be frequently updated to justify and support any long-term efforts.

3.2.3 DECOMMISSIONING OF NUCLEAR INSTALLATIONS

The EC has been conducting research into decommissioning of nuclear installations since 1979. The research may be considered mature and new techniques, for example in innovative remote handling and manipulation have been produced. The previous five years assessment pointed to some of the principal achievements, including particularly the publication of the "Handbook on Decommissioning of Nuclear Installations". However, the research area cannot be considered closed because no commercial nuclear structure has yet been fully dismantled.
The programme in FP4 followed the lines previously suggested, that is of generating data bases for various aspects of the dismantling process (the projects TOOL and COST), the development of a common methodology on decision making strategies and management of nuclear decommissioning projects and the further development of selected innovative cutting techniques (laser, plasma arc and water jet)
The current programme is reduced in size and focuses on transfer of knowledge for future decommissioning projects, the development of common strategies and the maintenance and accessibility of relevant databases. The main European Added Value is seen in speeding up the decommissioning process, maintaining a cutting edge capability in

relevant fields via international collaboration and increasing confidence in the EU that decommissioning is well understood and can be tackled economically with minimal radiation risk to workers and the public. One aspect that has not been considered so far is research needs associated with decommissioning many potentially activated installations, such as research accelerators. There may be a large number of these in the Member States that will require attention.

3.2.4 RECOMMENDATION.

The current focus of this small research area is seen as appropriate, and the continued support of networks and data and knowledge sharing is underwritten.

3.3 KEY ACTION 2: SAFETY AND EFFICIENCY OF FUTURE SYSTEMS.

This is a newly identified research area for FP5 with the objectives of assessing new or previously discarded reactor concepts that would offer advantages in terms of safety, economy, sustainability, waste generation and diversion. Relevant work had been undertaken in previous programmes, particularly in severe accident phenomenology and severe accident management. This is reported in section 4.1.2. That work has laid the foundation in terms of the necessary understanding of the physical and chemical processes of severe accidents so that a well-founded appreciation of future designs is now available.

In response to the first call for proposals in FP5 in June 1999, six projects and one concerted action were selected. For the later calls, the EAG has indicated that proposals for state of the art studies of applications of nuclear power other than electricity generation, such as heat production, desalination and hydrogen production, should be sought in order to maintain an overview of current developments. In addition, attention should be given to a more holistic approach to innovative design, integrating licensability and public acceptance at the outset.

There is an issue over projects concerning high temperature gas cooled reactor systems as they dominate the projects already awarded. These systems were vigorously developed through the 1960's and 1970's but then abandoned. There is renewed interest in other parts of the world and developments in technology means that there is a need to re-consider their potential for deployment later on in Europe. However, a full development programme will require a large, fairly long - term effort which seems rather unlikely in the present climate.

Recommendation

The development of evolutionary reactor designs should be driven by commercial considerations. There is a justification and need for common programmes concerning the longer-term development of innovative reactor designs.

3.4 KEY ACTION 2: RADIATION PROTECTION.

The legal basis for radiation protection regulation and research in the European Commission is laid down in the EURATOM Treaty of 1957. In particular it gives the Commission the responsibility to establish uniform "basic standards for the protection of the health of workers and the general public against the dangers arising from ionising radiation and ensure that they are applied". Regarding the research supporting this responsibility the Treaty states it should be a "study of the harmful effects of radiation on living organisms". The Treaty has a very broad coverage and provides the underpinning rationale for the research in this area. The objectives of the Key Action Area are specified as follows. To help operators and regulatory authorities to protect workers and the public during operations in the nuclear fuel cycle, to manage nuclear accidents and radiological emergencies, to restore contaminated environments and to improve competence in this area through training. These are therefore seen as being specifically end user oriented. It is important to note that the generic research in radiological sciences (section 4.5) covers the essential foundations of radiation protection and is fundamental to the activities in the key action area.

3.4.1 RISK ASSESSMENT AND MANAGEMENT

The basic radiation protection principles, such as justification, dose constraints and ALARA assume the establishment of a framework for assessing, managing and optimising safety; that means risk governance for all activities where workers or members of the public are, or might be exposed to ionising radiation. This area covers research projects aimed at underpinning such a framework. A number of computer codes have been developed for predicting the consequences of nuclear accidents and to assist in emergency management. The COSYMA code has been widely distributed inside and outside the EU. Continuing efforts to co-ordinate users' efforts and to maintain the code as state of the art are being made. This widely used code will continue to be supported under FP5 as an accompanying measure. The major RODOS code system is discussed separately under the heading "Off-site emergency management" in section 4.4.3.

It has become clear that a better quantification of risk and risk comparison has had only a limited impact on judgements as to risk acceptability. Social trust is now recognised as a pre-condition for any activity to be considered acceptable. The TRUSTNET concerted action has addressed risk governance through interdisciplinary activities at a European level aimed at understanding social organisation of risk taking and the preconditions for social trust. This work will continue in FP5.

Several social-psychological projects were carried out in the aftermath of the Chernobyl accident but, whilst scientifically very successful, did not help with the practical problems of the affected population in the re-establishment of safe living conditions. The ETHOS project offered an alternative approach to the centralised one, used by the authorities. It requires a strong involvement of the local population in the rehabilitation process; its success may be judged from the fact that the Belarussian authorities are to apply the approach widely. Lessons for Western European conditions are being considered in the EURETHOS project.

3.4.2 MONITORING AND ASSESSMENT OF OCCUPATIONAL EXPOSURE

Optimisation of all types of occupational exposure and dissemination of good ALARA practices within all sectors of the European industry and research involving ionising radiation is an essential part of risk governance. Important results of the work include recommendations on the implementation of ALARA in decommissioning strategies and operations and in the non-nuclear industry and research sector. These recommendations have resulted in specific actions in DG Environment, e.g. the organisation of workshops on "Good Radiation Protection Practices in Industry and Research" and on "Managing Internal Exposure". The ALARA-Newsletter has proven to be a very useful way to disseminate practical information and needs to be continued in future eventhough funds for it have not been identified in FP5.

3.4.3 OFF-SITE EMERGENCY MANAGEMENT

Experience gained after the Chernobyl accident clearly demonstrated the importance of improving administrative, organisational and technical emergency management arrangements in Europe. A lack of coherence contributed to the loss of public confidence. A key element in the research support to this EC need has been the development of the RODOS (Real Time On-line Decision Support for off-site emergency management) project. This has been under development for some time and the first pilot version for test operation was issued at the end of FP3. It has been further developed during FP4 to the point where it can now be implemented for operational use. 40 institutes from 20 countries in the East and the West have been involved in the project and some countries have already decided to install RODOS as a decision support tool in their national emergency centres.

RODOS offers a platform to share the development of a comprehensive decision support system applicable across Europe. It is vital that the users are fully involved in future development of the overall scheme, as well as individual components. It is important to note here that the users are likely to be experts on radiation safety related matters and not the real end-users, i.e. authorities and political decision-makers. The needs and expectations of these real end-users need more attention in future by means of e.g. exercises. There is also a need to ensure that the radioecology research community is involved in particular in the requirements for long term countermeasures.

For FP5 three projects have been approved; better decision support tools, better methods for assimilating information and handling uncertainty and managing disparate forecasts of medium/long range atmospheric dispersion. Economic and social questions still need more attention, as do environmental monitoring strategies that have not yet received sufficient attention.

3.4.4 RESTORATION AND LONG-TERM MANAGEMENT OF CONTAMINATED ENVIRONMENTS.

Much of the R&D in FP4 was conceived under the influence of Chernobyl and other situations of radiological significance in the former Soviet Union. It complements activities by DG Environment and work funded under the TACIS and PHARE programmes.

Radioecological research has been utilised more effectively in studies on restoration of radioactive contaminated areas than in the off-site emergency preparedness area above. Models have been developed to identify areas with high radio-caesium transfer because of specific uses of the environment. The emphasis in the projects has been varied; for example covering the self-help capacity of affected populations (RESTORE) and environmental and socio-economic responses to counter measures (CESER). The development of more holistic countermeasures strategies has made significant progress by integrating many aspects into the countermeasures selection process. Multi-attribute utility analysis has been used to rank restoration options at contaminated sites (RESRTAT) and additionally research has helped develop a management tool to assist decision making for restoration strategies for a range of urban, agricultural, semi-natural and forest environments taking into account the secondary effects and the produced waste (TEMAS). The further development of the model depends on the progress in radioecology, dosimetry and technical information on countermeasures. There is now a need to synthesise all relevant EC and national information for use in guides and supporting documents, and develop the models to be of more direct support to the decision-makers.

Recommendations

1. Global risk governance i.e. how to cope with different types of risk simultaneously, will continue to be important.
2. The handling of social and economic factors and innovative management techniques in decision-making processes needs further development and in particular to crisis management.
3. Monitoring, operational dosimetry, optimisation (ALARA) and case studies of internal exposure need more attention both in nuclear fuel cycle facilities (e.g. decommissioning), and in other industries such as those using Naturally Occurring Radioactive Materials (NORM), the radio-pharmaceutical industry and nuclear medicine services in hospitals.

3.5 GENERIC RESEARCH IN RADIOLOGICAL SCIENCES

3.5.1 RADIATION PROTECTION AND HEALTH

Estimates of the risks from exposure to ionising radiation are the basis of all radiation protection and they have to cover the extremely wide range of radiation types and exposure conditions in the natural environment, the workplace and the clinic to be of practical value.

Cancers and heredity effects have been studied in both FP3 and FP4. The emphasis in FP4 has been given to the development of a coherent approach combining the biophysics of energy deposition and induction of damage in DNA with the molecular biological investigation of the process involved in the repair of DNA damage. It also includes the cellular effects that mis-repair can cause and molecular biological analysis of the early events leading to the induction of cancer. This has given a deeper understanding of the mechanisms by which radiation exposure leads to the induction of cancer, and particularly to pre-disposition. As a final step the development of mechanistic models of the carcinogenesis process will be used to interpret epidemiological data.

Progress has also been made in the field of hereditary risk estimation as the result of the incorporation of advances in human molecular biology into the framework of genetic risk estimation.

Recent developments in gene research, molecular biology, irradiation techniques (single cell irradiation by soft energy microbeams without disturbing surrounding cells) and computer modelling provide exciting new possibilities to improve our knowledge of the dose-effect relationship at low doses where neither direct measurements nor epidemiological studies are applicable. More attention was paid to the promotion phase of the cancer process, where the role of suppresser genes in between two mutational steps was confirmed by molecular biology.

Understanding the mechanisms and modelling of the entire path from exposure to carcinogenesis has been developing fast and the models now have a good biological basis. Quantitative data suitable for modelling have been provided. Integration of experimental radiobiological work and theoretical approaches to develop mechanistic models of carcinogenesis has been successful. The experimental studies on the mechanisms underlying variation in DNA damage response and tumorigenic development were well represented in the FP4.

The post-radiotherapy second cancers in some inbred human populations were identified as a principal source of concern regarding genetic susceptibility. In particular, high dose medical irradiation at young ages may pose the greatest risk to such genetic cases. The question of the need for genetic testing for cancer susceptibility in the context of occupational exposures has also risen. The acquisition of knowledge on genetically determined radiation risk will be of significant importance in the further development of radiological protection standards. The whole area of DNA damage response and genetic susceptibility to radiation needs to continue in FP5.

New information on the neutron dose to the Japanese survivors has been obtained; specifically a possible underestimation of the neutron doses in the low dose region. The expected resolution of the neutron contribution to dose in Hiroshima is of crucial importance for radiation risk estimates and assessment of the current LNT (Linear-Non-Threshold)-model.

A better understanding of the mechanisms of radiation action at low doses and dose rates has been achieved through comprehensive mechanistic models for the induction by radiation of somatic late effects. The ultimate aim of these mechanistic models is to serve as a basis for extrapolation of epidemiological data to low doses and dose rates. The models are very promising for mechanistic understanding and improved dose extrapolation methods.

Important studies on childhood thyroid cancer were started in FP3 and this underlines the essential elements of continuity which characterise this area, especially as there is a need for follow up studies which will have to be organised 15 years after the exposure. This of course is provided that the material continues to be available.

The bone marrow transplantation approach that was unsuccessful in previous accidents is being replaced by methods currently under further development which involve growth factor treatment to facilitate the reconstitution of blood cell production and immune functions. It was demonstrated in these studies that thrombopoietin, if immediately administered, strongly counteracts radiation induced bone marrow damage by promoting reconstitution of immature stem cells and their direct progeny thereby making possible the response to other growth factors, and prevent profound thrombocytopenia and anaemia.

In FP5 the attention remains essentially focused on cancer. Five projects are funded concerning induction and repair of DNA damage, five projects addressing health effects of genome damage and predisposition to cancer and four projects addressing epidemiology and modelling of cancer.

Communication between researchers and the Article 31 group at joint seminars is welcomed and should be further developed as an excellent possibility of two-way communication. During the past ten years Europe, thanks to EC programmes has became the leader in many sections of basic radiological research with effective communication to the ICRP.

Well co-ordinated research groups and naturally grown networks were of great value for the effectiveness of the research in this area. Co-operation with the general health area in quality of life programmes could be beneficial. However, the type of co-operation and the benefits need to be carefully evaluated first.

Typical of this area of research presently is the very high speed of progress and therefore intense competition, so a rigid idea of concentrating all research in ”centres of excellence” may not be productive if the need of extremely expensive facilities does not require it.

3.5.2 ENVIRONMENTAL TRANSFER OF RADIOACTIVE MATERIAL

The strong impact of the special Chernobyl projects on the radioecological research in the regular FP3 programme highlighted the need to solve practical problems. In addition the complexity of the contamination situation forced the research groups into more interdisciplinary activities. It also showed that socio-economic and ecological consequences had to be considered alongside the radiological aspects.

Projects (e.g. PEACE, SAVE, SEMINAT, LANDSCAPE, ARMARA) dealing with the dynamics and migration of radionuclides, mainly caesium and strontium, and ecological models in different types of environments including agricultural, semi-natural, fresh water and Arctic marine environments, have been progressing well. Special success stories have been the models of radionuclide transfer from various types of soil to plants, based on deposition and soil characteristics, including soil solutions. The ability to model the dominating processes facilitates the prediction of caesium flux in an accident situation.

For FP5 two projects were approved concerning radionuclide behaviour in soils and one concerning aquatic ecosystems, namely re-mobilisation processes in marine sediments. Co-operation between modellers and experimentalists has been good, for example in the successful work on fresh water modelling (ECOPRAC, MOIRA). The overall objective of this work is the development of a mechanistically based, generally applicable whole-ecosystem model that can be applied in support of chemical and hydrological countermeasures mainly concerning caesium contamination.

Radioecology is moving more and more towards modelling the phenomena and the entire ecosystems. It is essential that models (and parameter values) are adapted to the local conditions and tested in the types of environments where they are expected to be used. The national end-users have to develop confidence in the models. The experience from the Chernobyl accident was not only the lack of models, but also the use of inappropriate models, e.g. not considering the impact of rainfall.

Notwithstanding the successes in the programme, a holistic approach to environmental radiation protection is still lacking. Other environmental non-nuclear contaminants, such as heavy metals, can be present together with radionuclides. Furthermore, only limited attention has been paid to NORM and no attention has yet been paid to the impact of radiation on other organisms. On the latter, it is important to be prepared to find a reasonable solution for the present social requirements to be able to demonstrate that other species, not only man, are sufficiently protected against ionising radiation. In FP5 one project has now been accepted for funding, that addresses the protection of non-human species.

It is essential in the future to synthesise the information gained in the Chernobyl and related radioecological studies and make it generally available. All of the end-user groups need to be taken into account carefully while making syntheses of the results and guidance based on them.

Experimental and field studies in radioecology are the best way to maintain preparedness in know how and measuring capabilities for accidental situations.

3.5.3 INDUSTRIAL AND MEDICAL USES AND NATURAL SOURCES OF RADIATION

FP4 focussed on medical uses and natural radiation; the industrial use was restricted to nuclear energy. The Basic Safety Standards require application in the non-nuclear energy sector where significant radiation protection issues occur. An example of this is in phosphate industry. However no projects have covered this topic to date. The Patient Directive 97/43/EURATOM legally requires the use of optimisation in diagnostic radiology. The work in the recent programmes has concentrated successfully on optimisation in radiography (intervention radiography (IR), paediatrics, Computer Assisted Tomography (CT), and fluoroscopy) as well as addressing image quality criteria.

The population is exposed to higher levels of exposure from medical radiology than from any other man-made source of ionising radiation. The revised EC Patient Directive introduces a number of new and extremely relevant requirements into the legal framework of radiation protection of persons who undergo medical exposures. As children are substantially more sensitive to adverse effects of radiation than adults a number of studies were carried out in order to develop guidance on paediatric radiology which resulted in European Guidelines on Quality Criteria for Diagnostic Radiographic Images in Paediatrics. These included both patient dose and image quality criteria. Also Quality Criteria for Computed Tomography were developed for adults in a previous FP but not for children. The work continued in FP4 by extending the quality criteria to a selection of common fluoroscopic and CT examinations on children and provided a practical methodology for defining image quality and patient dose criteria. Two draft quality criteria documents have been prepared which could be used as draft working documents and further developed into more complete European Guidelines in the FP5.

Computed Tomography is contributing up to 40% of the collective effective dose from diagnostic radiology in some EU countries and use of it is expanding. Therefore, a revised version of European Guidelines on Quality Criteria for Computed Tomography has been developed and delivered to the EC for printing. Funds for publication of some guidelines has been a problem and needs to be solved in future in order to fully exploit the results.

New devices and developments in interventional radiology and vascular brachytherapy tend on the one hand to increasing radiation doses, and yet on the other imaging is faster. Therefore it is important to continue efforts at optimisation. An important conclusion is that improved risk-related dose quantities are required for routine application in diagnostic radiology.

Only two projects were accepted for funding in FP5 on medical applications, one concerning clinical requirements for x-ray imaging and another to underpin the Patient Exposure Directive in relation to justification, optimisation and reference levels. In addition one concerted action on optimisation of CT practices was approved.

Radon is the largest contributor to the radiation dose to the public. However, the question of risk from in-door exposure to radon has not yet been resolved. The basis for current risk estimates are from underground miners and these are obtained in conditions very different from those in dwellings. Pooling of European and USA epidemiological studies in dwellings is important. In FP3 and FP4, extensive studies were carried out with good results in lung modelling, aerosol behaviour, retrospective dosimetry, epidemiology and intercomparison of passive radon detectors as well as techniques for reduction of radon exposure. It is important that the work on radon risk is continued in FP5 and beyond to find a satisfactory solution. And we note that in FP5 only a conference was approved. However, the identified need for further work concerning radon risks should not be allowed to delay European policy decisions on protection against radon.

3.5.4 INTERNAL AND EXTERNAL DOSIMETRY.

Radiation protection and the effective use of radiation in medical applications requires the capability to accurately quantify the characteristics and extent of radiation exposure so that appropriate assessments of the potential health consequences and risks can be formulated. The International Commission on Radiation Units and Measurements (ICRU) is making international recommendations on these quantities and how to deal with various measuring problems. The work is partially based on EC projects on these subjects. During FP4 work has covered dosimetry of external beta rays, conversion coefficients for photons, neutrons and electrons, proton dosimetry and nuclear data for neutron and proton beam therapy etc.

Assessment of the radiation doses and risks associated with exposure to air born radionuclides requires quantitative information on the deposition of inhaled material in each region of the human respiratory tract and on the pathways of clearance. The ICRP Human Respiratory Track Model (HRTM) has been used to calculate dose coefficients for inhalation of radionuclides that have been adopted into the BSS Directive. However, important uncertainties remained in the assumptions made in the HRTM and this work continued in the FP4 and will have to continue in the future. In FP4 specific progress was made e.g. regarding the particle deposition in the lungs and the clearance from the respiratory tract.

An extensive database of dose coefficients was published to meet the demands of health physics practitioners and researchers in radiological protection and the database was adopted by ICRP.

Computer codes have been developed to calculate bioassay data for acute and chronic exposures for the use in assessing intakes. Because of the free movement of people in Europe it is important to have a common standard for monitoring with personal dosimeters and monitoring for internal doses, as well as the same requirements defined by the BSS Directive and Patient Directive.

To improve the dosimetry of low energy photon radiation, beta radiation and mixed photon and neutron fields several new dosimeters were developed either to prototype or to commercial level. A real breakthrough was achieved in mixed neutron detection that has important commercial possibilities (proportional counters and cheap solid state pin diodes), although the size of the potential market is small.

The implementation of BSS to air crew exposed to cosmic radiation (which is specified as occupational exposure), posed a practical radiation protection problem because of the complex radiation field. This work has been a good example of multidisciplinary co-operation that resulted in a practical solution for worker dose control in the implementation of the BSS. This work will continue in FP5 addressing the exposure of aircrews during solar maxima.

Recommendations.

1. Quantification of radiation effects is still of vital importance and therefore requires a continuing research effort.
2. Genome projects, involving both human and animal studies, genetic susceptibility in particular in high dose areas and epidemiological studies with appropriate available groups should continue.
3. Possible fingerprints of the origin of cancer cells would be valuable.
4. Existing exposed groups e.g. for thyroid cancer need to be followed for sufficient time.

   Retrospective dosimetry should be improved in order that epidemiology can be successfully interpreted.
5. The concept of dose as a means of reflecting risk is not ideal, and efforts need to be made to improve the concept and the measuring instrumentation accordingly.
6. A holistic approach to environmental protection is still missing and needs further work to cover both non-human species and non-nuclear and nuclear contaminants in the same framework.
7. Societies' expectation for further reductions in the releases of radionuclides into the environment requires a balance between various aspects (health protection, technical, social, economic, and different sectors of the environment) in order not to do more harm than good. Preparing for the implementation of the OSPAR (Oslo-Paris) convention is one such example.
8. Co-operation with the general health area in quality of life could be beneficial as long as potential contributions can identify added value.
9. In the medical field optimisation of exposure of patients and medical staff should be developed in order to reduce risk, in particular with relation to new technical developments.

3.6 KEY ACTION 2: SUPPORT FOR RESEARCH INFRASTRUCTURE.

This is a new activity in FP5. Its objectives are to enhance access to and improve the consistency of the nuclear research fabric within the Community so that optimal use can be made of the available resources to the competitive advantage of European industry, and to continue ensuring the safe and acceptable exploitation of nuclear technologies. Three priority areas are identified in the programme: large scale facilities, networking and databases and tissue banks.

Proposals so far received have focused solely on networking and data bases/tissue banks. The absence of proposals on access to large-scale facilities was surprising but was probably a result of this topic not having featured in previous Euratom programmes (albeit featuring in previous EC programmes). With the maturity of nuclear energy and its limited market prospects, many large scale nuclear research facilities are being decommissioned, both in Europe and elsewhere; access to those remaining will, therefore, become increasingly important and this topic should be given greater prominence.

Networking remains a key feature of the programme. A better distinction needs, to be made between networking generally (i.e., thematic networks) and that under the section of the programme concerned with support for research infrastructure; this was a source of some confusion in the first calls for FP5. The importance of effective networking for the success of the programme as a whole cannot be over-stated and its role and importance should, therefore be reinforced. In particular it should be aimed at:

- providing better co-ordination of Commission and nationally sponsored research and training
- promoting more effective collaboration and feedback between the research and user (industry and regulatory authorities) communities
- achieving consensus or convergence of views on key issues with industrial, public acceptance and/or European policy implications
- strengthening and stimulating an efficient European nuclear research infrastructure
- exploiting strategic research carried out in Europe
- promoting more effective cross-discipline research
- providing better access to and making more effective use of important or unique nuclear facilities

The scope and nature of networks supported by the programme will, however, be largely determined by what is proposed by the research community. This may be insufficient, in either scope or content, to secure the programme objectives. In these cases, the Commission Services may need to be more pro-active (without, however, compromising the principle of equity of opportunity for those making proposals) and take additional steps to achieve the required level and quality of networking. This may take various forms. At an informal level, potentially interested organisations or groups of organisations may be encouraged to take initiatives in a particular area or areas; in some cases a more formal approach may be needed, for example a dedicated call for networking in particular areas or networking of particular types.

Recommendations:

1. To give greater prominence to this part of FP5.
2. Networking is a potentially important future direction for Commission activities. It should be followed up vigorously, but with the specific requirements of thematic and facility based networks clarified. The Commission staff should be more pro-active in both explaining the rationale for networks and in kick-starting particular networks.

4 The current situation concerning FP5

In the specific programme nuclear fission safety, the objectives are very broad and as we have shown in the introduction have not changed significantly for some years. We can therefore say that some objectives are still relevant even if not all of them can be addressed by a programme that is resource limited. The current position for FP5 is that a first set of calls was made in June and October 1999 and about 60% of the funding for the whole programme was utilised. As a result some 130 projects have been selected. Two further calls are envisaged (January 2001 and 2002). This allows for a reorientation of the programme in response to analysis of the responses to the first call (i.e. how well they covered the objectives of the programme), and to take into account recent S&T developments and social demands.
The response to the first call was patchy. As we have said, the change in structure has lead to some confusion, and the research community did not properly understand the inclusion of new actions such as Support to Research Infrastructure. Not surprisingly, responses in those areas were disappointing. In radiation protection particularly the split between key action and generic Research caused considerable problems which were exacerbated by staff reductions. However, we welcome that many of these issues have been picked up by the EAG in its review of the work programme for the second call.

5 Recommendations from the previous 5 years assessment.

The previous assessment made a number of recommendations, both general (10 in all) and in the specific Research areas (27 in all). We cover the specific Research areas in the relevant sections above, and here give some overall observations concerning the previous recommendations.
In general terms, the previous recommendations <u>are</u> reflected in the way in which FP5 was developed. This is certainly true for the detailed scientific aspects. It is clear that many important questions have been brought close to their solution and that FP5 is providing a closure pathway in many cases. It is also clear that the "problem solving" nature of the research characterising FP5 goes a long way to implementing the previous recommendations in this context. The involvement of other end users, such as DG's Environment and Energy is an on-going requirement
The question of closure criteria, however, remains. This Board believes that closure criteria should be treated with caution, as they vary from discipline to discipline and each aspect should be judged on its merits and on the prevailing situation of the research in that field at the time.
It is recognised that scientific quality must remain a priority, given, of course, that it must be paralleled by fully professional project management and leadership. The Annual Monitoring Reports have continued to emphasise this point. The new arrangements for evaluating proposals against scientific quality as well as programme objectives are an important contribution to this continuing quest for scientific excellence.

The relationship between the SP "nuclear fission" and the research activities carried out in the same field by the JRCs has remained opaque. This too has been reflected in the

Annual Monitoring reports from the intervening years. There are some indications that changes in structure in DG Research and the overall management of the JRCs are leading to greater transparency, but the Board believes that much more is needed to be able to demonstrate that obvious co-ordination and common goals are well established. The recent closure of the FARO facility is a case in point. The new JRC in Seville should be encouraged to take up technical developments relevant to this SP and in addition it could assist DG Research in implementing the social and economic aspects of the programme.

The recommendation to make greater use of association agreements has been overtaken by the decision that they are no longer allowed. This does not detract from the spirit of the recommendation and we recommend a greater devolution of authority (technical and financial) to project co-ordinators, especially in the light of many concerns expressed to us about the shortage of manpower in DG Research.

The continuation of 100% funding for Universities and Hospitals has been achieved, but the whole question of the level of contribution from EU funds needs to be reconsidered in the light of the principles espoused in the "European Research Area" concept. The use of concerted actions as a means of both information gathering and strategic planning by DG Research staff is to be encouraged.

The recommendation on the need to peer review periodic reports has not been implemented and we make our own recommendations concerning review and "valorisation" of projects both during their implementation and post-job.

The need to pay particular attention to dissemination and communication is well recognised by DG staff, nevertheless, whilst scientific dissemination is generally excellent, communicating the value and context of the work to decision-makers and the public is less so. It needs to be recognised that communicating sometimes difficult scientific and technical research results to non-technical recipients is a professional task and some fraction of the resources should be made available to "add value" to work done by making it more accessible.

Greater co-operation is being achieved with high level scientific institutions outside the EU, principally through the internationalisation of large-scale projects. In some areas this could be improved, and in particular, a better-formalised relationship with the USA in radiation protection and waste management would be valuable. Many EU Member States and EU funded experimental facilities are identified in the recent OECD/NEA study on Safety Research facilities and capabilities worldwide (SESAR/FAP). Interaction with CEEC countries is now assured through the many activities associated with accession.

6 Overall Conclusions and Recommendations

This section summarises the overall conclusions and recommendations of the Board. Detailed conclusions and recommendations concerning the individual topic areas are given at the end of the respective sections.

1. The overall objectives of the Commissions Specific Programme of Research and Training in "Nuclear Fission" have been met by the programmes implemented in the FP3 and FP4 and are likely to be met by the current programme FP5. The evolution of these programmes has shown that the research performed has been flexible enough to respond to changing needs, whilst at the same time providing a degree of continuity and support for research efforts requiring time to deliver results. However we must say that the trend of reducing support to these

programmes during the period covered has put constraints on its capability to meet all of the objectives. In conclusion, we believe that a forward programme of Research into FP6 and beyond would be cost effective and a prudent investment given the overall objectives of Commission funded research.

2. The fact that radiation protection is covered by two separate parts of the programme caused confusion. We therefore suggest that Radiation Protection be grouped with Generic Research in Radiological Sciences separately from Nuclear Fission.
3. To improve the coherence and effectiveness of the programme in future it is necessary to develop a "vision" for European Research in the SP of Nuclear Fission and Radiological Sciences, and to back this up with a strategic approach which is transparent and widely supported by the technical community and decision makers. The staff of DG Research should be given a much more pro-active role in developing and implementing such a strategy. Calls for proposals in future should strongly reflect the needs of research to implement that strategy.
4. We recommend that the needs for training (in the broadest sense) should be given a higher priority in future. This should begin with a clear statement of the strategic aims of such activities. The well being and safety of the nuclear activities in Europe depend upon a continuing supply of well-trained and highly motivated scientist and technologists.
5. The Board supports the concept of "European Centres of Excellence". These should be identified in the areas of competence of the nuclear fission specific programme and, wherever appropriate, should build on existing centres in EU Member States (including Applicant Countries). However, it may have serious drawbacks in building monopolies, reducing competition and possibly reducing national interests in financing research. The concept must, therefore be implemented with great caution and only in specific areas where the advantages clearly dominate.
6. The creation and support of networks as a means of increasing co-operation and dissemination of information is strongly encouraged. It has already been successfully implemented in a number of areas of the programme with good effect.
7. The Advisory Committees (STC, CCE and EAG) each have their place, but more needs to be done to encourage communication between them and to optimise the use of the large pool of experience and knowledge available through them.
8. A number of new research tools have been developed in this specific programme which are either clearly more widely useful, or have even been developed in parallel elsewhere. DG Research should first identify common areas of Commission funded programmes and second, perhaps by sub-contracting, ascertain more widely distributed opportunities. A policy of "joined up research" should be an important aim for the future.
9. Continued vigilance is required to maintain the current often generally excellent dissemination of results in the scientific community. Communicating the value of the research, and its context in supporting Commission objectives is a job for professional communicators and more use needs to be made of them in getting the message to decision-makers and the public.
10. Where large projects are let, the project co-ordinators need to be given clearly defined responsibilities and sufficient freedom and resources to manage them, subject to an appropriate level of audit.
11. Insufficient attention is given to post job evaluation and to the consolidation of research output into a coherent body of information supporting end users in the

field. In addition, a larger fraction of resources should be devoted to the storage/data banking and general husbanding of hard won research results.

12. We recognise that this research programme is paid for by taxpayers in the Union and that in consequence it must be subjected to audit and scrutiny. However, we believe that there is a significant danger of "assessment overload". The advisory committees review progress and strategy, there is an annual monitoring activity and this 5-year assessment. In addition, there are numerous scientific and technical evaluations available in the different areas. It would be reassuring to see an assessment of the system of reviews, perhaps conducted by the STC to ensure that the most efficient process is undertaken.
13. Further Research on P&T-systems should be evaluated and grouped in the category "Safety and efficiency of Future Systems".
14. A common theme emerging from many of the research areas is risk governance, That is how to manage activities where the overall risk is made up of contributions from many factors, including both technical and social. Developing an understanding of such complex systems is not limited to nuclear activities and we recommend that very broad inter and multi disciplinary studies are undertaken by the Commission as a horizontal activity.

ANNEX 1

Terms of Reference

ANNEX 2

Conversion Table for FP4 to FP5

. The panel is requested to comment on the outputs of the previous programmes, but in the structure of FP5. Therefore we have used the following table to show the link between the programme headings of FP4 and FP5 in Nuclear Fission Safety. We have not attempted to include headings from FP3 as these have already been subsumed into the FP4 format.

FP5 Key Actions	**FP4 Programme Areas**
Operational safety of existing installations. 1. Plant life extension 2. Severe accident management 3. Evolutionarily concepts.	A. Exploring innovative Approaches Conceptual reactor safety features B. Reactor Safety In-vessel core degradation and coolability Ex-vessel corium behaviour and coolability Source term Containment performance Energetic containment threats
Safety of the fuel Cycle Waste and spent fuel management and disposal Partitioning and transmutation Decommissioning of nuclear installations	A. Exploring innovative Approaches Partitioning and transmutation C. Radioactive Waste management and Disposal and Decommissioning Safety aspects of waste disposal Underground research laboratories Research on basic phenomena Decommissioning of nuclear installations.
Safety and Efficiency of future systems 1. Innovative systems 2. Revisited systems	A. Exploring Innovative Approaches Partitioning and Transmutation
Radiation Protection 1. Risk assessment and management 2. Monitoring and assessment of occupational exposure 3. Off-site emergency management 4. Restoration and long-term management of contaminated environments.	D. In part E. Mastering Events of the Past Recognition and amelioration of health effects Restoration of severely contaminated territories Management and disposal of radioactive waste Emergency management approaches Data management Public information.
Generic Research in Radiological Sciences	**FP4 Programme Areas**

1. Radiation protection and health 2. Environmental transfer of radioactive material 3. Industrial and medical uses and natural sources of radiation 4. Internal and external dosimetry.	D Radiological Impact on Man and the Environment Understanding radiation mechanisms and epidemiology Evaluation of radiation risks Reduction of exposures. E. In part
Support for Research Infrastructure	**No equivalent in FP4**

Table showing the relationship between the key action areas of FP5 and the programme areas of FP4. It is difficult to give a one to one correlation for all of these areas, but the ongoing themes of the research are seen to be maintained, even though the structure of the programme is different.

ANNEX 3

Evolution of Programme Objectives from FP3 - 4 - 5

Framework Programme	Summary of basic objectives.
FP3 (1990-1994)	The aim of this section (nuclear fission safety) is to continue the common endeavour to support Member States in the fulfilment of their responsibilities for regulating and protecting the environment. Community action will foster a harmonised approach to safety by bringing together all the parties involved, this reinforcing the prenormative dimension of research. A new impulse will be given by concentrating research on reactor safety with greater attention to passive technologies, radioactive waste management, decommissioning operations, intervention in a hostile environment, fuel elements, actinides and control of fissile materials. Radiation protection research will cover radiation from natural and medical sources, a better definition of the risks of low radiation doses and new technologies to assess quickly the radiological consequences of nuclear accidents.
FP4 (1994-1998)	The objective is to ensure the safety of all nuclear activities whatever they are, the production of electricity from fission, the use of radioactivity or ionising radiation, or the presence of natural radioactivity. In spite of the progress achieved by the electricity industry, the accident at Chernobyl has highlighted the need for research on specific topics in collaboration with the nuclear safety community in central and eastern Europe. It is necessary to consolidate the nuclear option by showing our ability to control in all areas of application. This demonstration of a full nuclear safety capability will be made through four priority areas; • The development of a dynamic approach to nuclear safety contributing to the consolidation of a safety culture on a world scale. • The joint use of the large European facilities to arrive at a better understanding of the crucial phenomena linked to the nuclear fuel cycle and waste. • Pursuing the development of nuclear safeguard techniques. • The integration of radiological protection into a global system for the protection of man and the environment.
FP5 (1998-2002)	To enhance the safety of Europe's nuclear installations, to improve the competitiveness of Europe's industry, to ensure the protection of workers and the public from radiation and to help solve waste management and disposal problems. To consolidate and advance, through generic research, European knowledge and competence in several areas concerning radiological protection and health.

ANNEX 4

Summary of Basic Objectives of FP 5 Specific Area: Nuclear Fission and Generic Research in Radiological Sciences

FP5 Key Action 2	**Summary of basic objectives**
Operational Safety of Existing Installations	To provide improved and innovative tools and methods for maintaining and enhancing the safety of existing installations, for achieving evolutionary improvements in their design and operation and for improving the competitiveness of Europe's nuclear industry.
Safety of the Fuel Cycle	To develop a sound basis for policy choices on the management and disposal of spent fuel and high-level and long lived radioactive wastes and on decommissioning and to build a common understanding and consensus on the key issues.
Safety and Efficiency of Future Systems	Investigate and evaluate new or revisited concepts for nuclear energy that offer potential longer term benefits in terms of cost, safety, waste management, use of fissile materials, less risk of diversion and sustainability.
Radiation Protection	To help operators and safety authorities to protect workers, the public and the environment during operations in the nuclear fuel cycle, to manage nuclear accidents and radiological emergencies and to restore contaminated environments.
Support for Research Infrastructure	To make optimal use of, enhance access to and improve the consistency of the European research fabric of infrastructures (large facilities, networks of distributed facilities, infrastructural centres of competence) to the extent that such measures are not undertaken by other aspects of the framework programme. To this end, measures are envisaged to help researchers with trans-national access to infrastructures that are of Community wide interest on account of their rarity and/or specialisation.
Generic Research in Radiological Sciences	The emphasis is on understanding and awareness of the hazards related to ionising radiation and radioactivity. More especially the effects of low-dose radiation, particularly on humans, and including epidemiology studies. On the environmental transfer of radioactivity, enhancing the safety and efficacy of medical and industrial uses of radiation and better assessment of exposures from sources of natural radiation, and to improvements in internal and external dosimetry.

ANNEX 5

Overall trends in funding from FP3 to FP4 to FP5

Topic Area	FP3 (89-94)	FP4 (94-98)	FP5 (98-02)
Operational safety of existing installations.	15.3	42.4	37.0
Safety of the Fuel Cycle			
Waste Management	71.7	32.5	31.0
Partitioning and Transmutation	4.8	5.8	26.0
Decommissioning	39.6	3.7	2.0
Teleman Project	23.9	-	-
Safety and Efficiency of Future Systems	-	4.8	12.0
Radiation Protection and Generic Research in Radiological sciences	62.4	57.0	49.0
Support to Infrastructure	-	-	9.0
Total	217.7	146.2	166.0

Note that these figures are derived from information from the various programmes that are made on different bases due to changes in the structure of the programme. In particular we should note

1. Reactor safety includes 13 MEuro for the PHEBUS experiment in FP4, even though this was administered through the JRC programme. In FP5 this is 4 MEuro.
2. Partitioning and transmutation is included in innovative approaches in FP4 and in Safety of the Fuel Cycle in FP5. In FP5 this amounts to 26 MEuro. This means that the trend in funding for this area over the three programmes has been 116.1 - 37.2 - 31.0 MEuro. This includes decommissioning activities that were previously identified separately.
3. Not included here are 23 MEuro for Radiation Protection projects directly related to the Chernobyl accident, which were outside the framework programmes.
4. In FP 4, there has been some funding of researchers in the from the INCO-COPERNICUS programme of about 9 MEuro.

ANNEX 6

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In addition to the reports distributed to the entire Panel, 63 summaries of final reports and publications were received on Radiation Protection matters:

ANNEX 7

List of Experts interviewed by the Assessment Panel

L.Baetsle	Chairman OECD/NEA Expert group on P&T 1996-1998	Belgium
G.Colard	SCK.CEN, Mol	Belgium
C. Desaintes	SCK.CEN	Belgium
P. Jacquet	SCK.CEN	Belgium
J.Marivoet	SCK.CEN	Belgium
B.Neerdael	SCK.CEN	Belgium
S. Pilate	Belgonucleaire/EDF	Belgium/France
A. Poffijn	RUG/DBIS	Belgium
M.Put	SCK.CEN	Belgium
P. De Saint-Georges	SCK.CEN	Belgium
P. Van Iseghem	SCK.CEN	Belgium
H. Vandenhove	SCK.CEN	Belgium
Mr. Vanmarcke	SCK.CEN	Belgium
G. Volckaert	SCK.CEN	Belgium
A. Wambersie	UCL Woluwe. ICRU	Belgium
H. Zeevaert	SEK.CEN, Mol	Belgium
M. Annanmaki	STUK	Finland
L. Mattila	VTT	Finland
T. Jaakkola	University of Helsinki	Finland
T. Rahola	STUK	Finland
K. Sinkko	STUK	Finland
M. Tapiovaara	STUK	Finland
H. Tuomisto	FORTUM, Vantaa	Finland
T. Turtiainen	STUK	Finland
B. Wahlstrom	VTT	Finland
F. Besnus	IPSN	France
H. Boussier	CEA, Marcoule	France
Mr. Brechignac	IPSN	France
J-F. Dozol	CEA Cadarache	France
L. Granger	EDF	France
C. Lefaure	CEPN	France
M. Livelant	Director IPSN, past Chairman CCE Fission.	France
G. Monchaux	CEA	France
J.P. Schapira	IN2P3 - CNRS	France
Ms Schieber	CEPN	France
A. Sugier	IPSN	France
M. Tirmarche	IPSN	France
Mr. Winter	IPSN	France
Mr. Atkinson	GSF	Germany
W. Bechthold	FZK	Germany
W. Brewitz	GRS	Germany
C. Broeders	FZK	Germany
T. Bucherl	Technical University of Munich	Germany
G. Buckau	FZK	Germany

Mr. Ertel	GSF	Germany
Mr. Harrison	GSF	Germany
Mr. Heidenreich	GSF	Germany
E. Hicken	FZJ Julich	Germany
Mr. Jacob	GSF	Germany
T. Kanzleiter	Battelle, Escborn	Germany
A. Kellerer	University "Ludwig-Maximilians" of Munich, GSF	Germany
G. Kim	INE, FZK	Germany
H Paretzke	GSF	Germany
Mr. Ross	University "Ludwig-Maximilians" of Munich	Germany
T. Rothfuchs	GRS	Germany
W. Steinwartz	Siempelkamp	Germany
R. Storck	GRS	Germany
W. Von Lensa	FZJ. Julich	Germany
Mr. Verner	GSF	Germany
Ms. Voigt	GSF	Germany
F. Huertas	ENRESA	Spain
S. Bjurstrom	SKB. Chairman STC	Sweden
V. Frid	SKI	Sweden
W. Gudowski	RIT Stockholm	Sweden
O Olsson	SKB	Sweden
B, Raj Sehgal	RIT Stockholm	Sweden
C Svemar	SKB	Sweden
P. Wikberg	SKB	Sweden
B. Bowsher	AEA Technology Winfrith	UK
R. Clarke	NRPB Chilton , Chairman ICRP	UK
R.Cox	NRPB Chilton	UK
A. Edwards	NRPB Chilton	UK
M. Gardiner	AEA Technology Harwell	UK
D. Lloyd	NRPB Chilton	UK
J.C.H. Miles	NRPB Chilton	UK
C. Muirhead	NRPB Chilton	UK
D. Pooley	Former Chairman STC	UK
W. Rodwell	AEA Technology Harwell	UK
J. Simmonds	NRPB Chilton	UK
B. Stather	NRPB Chilton	UK
B. Wall	NRPB Chilton	UK
M. Williams	AEA Technology Harwell	UK
W. Kickmaier	NAGRA	Switzerland
P. Zuidema	NAGRA	Switzerland

COMMISION STAFF MEMBERS INTERVIEWED BY THE ASSESSMENT BOARD

DG RTD.

H. Forsstrom	Head of Unit/scientific officer
J. Martin Bermejo	Scientific officer
V. Bhatnagar	Scientific officer
H. Bischoff	Scientific officer
Z. Centelles	Scientific officer
K. Chadwick	Scientific officer (Retd.)
M. Desmet	Scientific officer (Retd)
T. McMenamin	Scientific officer
G. Van Goethem	Scientific officer
N. Kelly	Scientific officer
B. Haytinck	Scientific officer
M. Hugon	Scientific officer
P. LeMaitre	Scientific officer
T. McMenamin	Scientific officer
M. Menzel	Scientific officer
H. Ritter von Maravic	Scientific officer
E Schulte	Scientific officer
J. Sinnaeve	Former Head of Radiation Protection

DG JRCs.

S Crutzen	Officer in charge of the co-ordination of nuclear activities
A. Jones	JRC Ispra.
J-P. Glatz	JRC-ITU
D M. Jansens	JRC-ITU
R. Konings	JRC-ITU
J. Magill	JRC-ITU
B.Sätmark	JRC-ITU
R. Schenkel	JRC-ITU

ANNEX 8

Panel Members

Panel Member	Background
Louis Patarin. Chairman	Former R&D Director COGEMA. Former Director Chemistry Division CEA. Professor, National Institute for Nuclear sciences and Techniques.
Michael R Hayns. Rapporteur and Reactor Safety	Formally Director Advanced Systems and Safety. AEA Technology Formally POWERGEN Professor Aston University. Visiting Professor University College London Former Chairman CGC5 (CCE) Member of the External Advisory Group on Nuclear Fission Safety.
Anneli Salo. Radiation Protection	Formerly Director of the Surveillance Department STUK Finland. Formerly Section head of the Radiation Protection Section in IAEA. Member of National Council for Nuclear Waste,Sweden President Nordic Society for Radiation Protection.
Per-Eric Ahlstrom. Partitioning and Transformation	Retired in 1997, Vice-President of SKB 1993-1997, Research Director of SKB 1984-1993. Now senior consultant for SKB. Over 43 years of professional experience in the nuclear power industry - reactor physics, nuclear engineering, reactor safety and nuclear waste management.
Gilbert Eggermont. Radio active Waste.	Advisor to the Board and Programme Manager of SCK.CEN,Mol, visiting Professor at the University of Brussels(VUB), former Vice-President of the Board of NIRAS.ONDRAF.