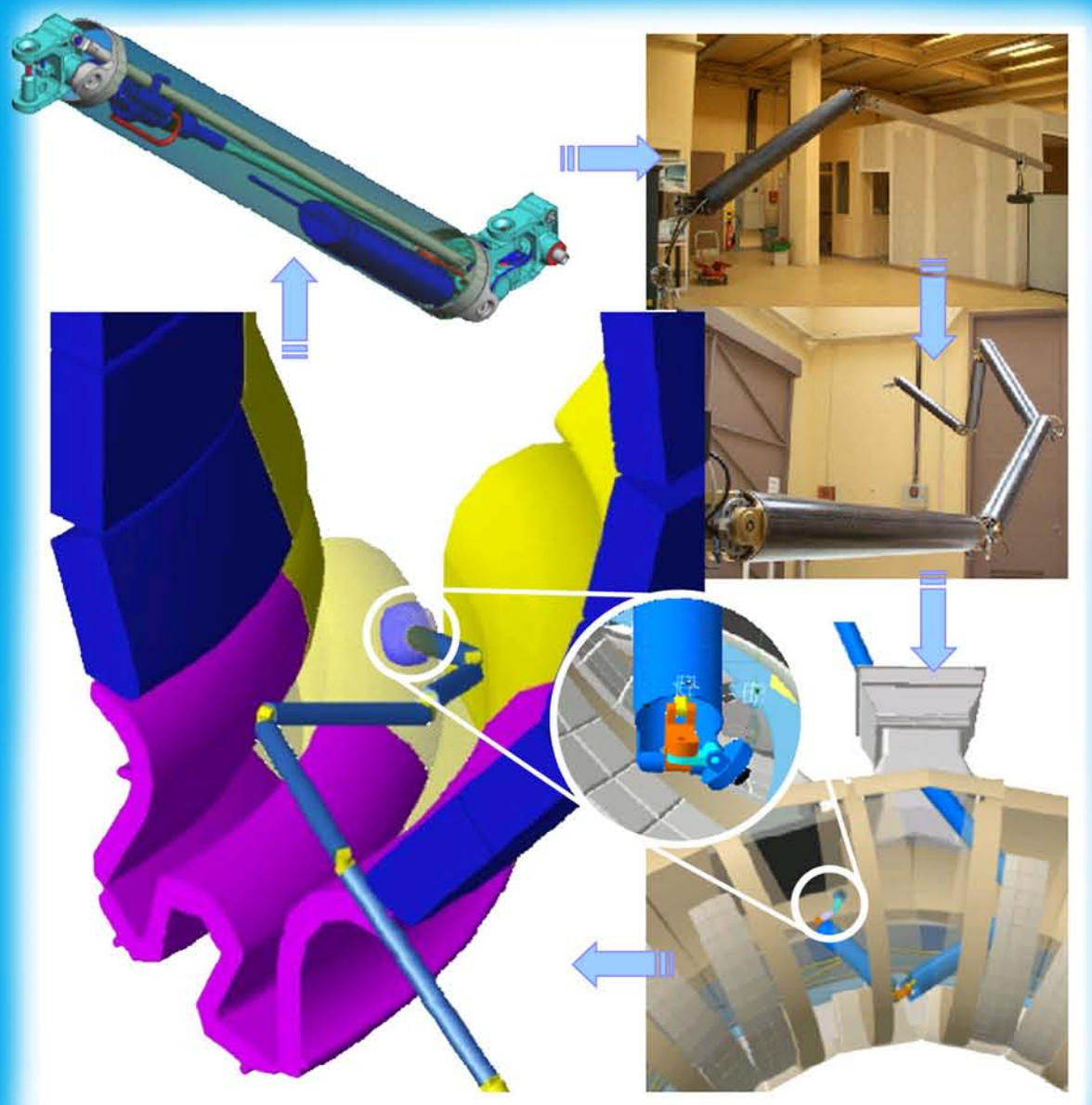
FUSION TECHNOLOGY

Annual Report of the Association EURATOM-CEA 2004

(full report)

Compiled by : Ph. MAGAUD and F. Le VAGUERES



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Cover : *The Articulated Inspection Arm (AIA), an articulated multipurpose tool to demonstrate the feasibility of close inspection of the ITER Divertor cassettes and Vacuum Vessel first wall. The AIA is able to operate under temperature (120°C) and vacuum (10^{-6} Pa).*

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Design Support

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Heating Systems

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Vessel-In Vessel

Plasma Facing Components

Safety and Environment

Heating Systems Technology Project

UNDERLYING TECHNOLOGY PROGRAMME

Vessel-In Vessel

Plasma Facing Components

Remote Handling

Tritium Breeding and Materials

Breeding Blanket

Materials Development

Structural Materials

Safety and Environment

INTRODUCTION

European research on controlled thermonuclear fusion is carried out in an integrated programme with the objective to develop a safe, clean and economically viable energy source. Part of this programme is under the responsibility of the *European Fusion Development Agreement* (EFDA) which provides a framework covering the activities in the field of technology (both Next Step and Reactor) and the collective use of the Joint European Torus (JET).

This annual report summarizes activities performed by the Euratom-CEA Association in 2004 within the frame of the European Technology Programme (both "EFDA" activities and "Underlying Technology" programme). It does not include keep-in touch activities in the frame of Inertial Confinement Energy, reported in a specific issue performed by the European Commission.

This full report is also available on line at "*http://www-fusion-magnetique.cea.fr*". In each section, the tasks are sorted out according to the EFDA main fields : Physics (TP) , Vessel/In-Vessel (VIV), Magnets (TM), Tritium breeding and Materials (TT), Safety and Environment (TS), System Studies (TS), JET technology activities (TJ),… The Euratom-CEA Association is involved in all these topics (figure 1).

- Euratom-CEA activities carried out in the field "***Physics Integration***" are mainly linked to neutral beam developments and to the development of diagnostic components. In particular, in-situ diagnostics of the plasma facing surface have been studied.

- Plasma Facing Component (PFC) developments, Vacuum Vessel/Blanket activities and Remote handling studies are carried out inside the field "***Vessel/In-Vessel***". The manufacturing of the ITER Primary First Wall (PFW) panel by HIP forming has been investigated. A dummy mock-up was produced to validate the manufacturing feasibility.
  In collaboration with BAE Systems, the Euratom-CEA Association has investigated a new welding process, able to improve welding productivity by several times compared to the ITER welding reference process. It is based on a hybrid laser/TIG process called Hybrid Laser Conduction Welding (HLCW).
  A ITER first wall mock-up (a combination of copper alloy as heat sink material, stainless steel as structural material and beryllium tiles as an armour material) have been successfully manufactured using induction brazing. This process limits the over-temperature exposure of the CuCrZr copper alloy.
  The Euratom-CEA Association performs a R&D program to demonstrate the feasibility of close inspection of the ITER Divertor cassettes and Vacuum Vessel first wall. The work performed includes design, manufacture and testing of an articulated multipurpose tool demonstrator called Articulated Inspection Arm (AIA), able to operate under temperature (120°C) and vacuum (10^{-6} Pa). In 2004, a single module prototype was manufactured and successfully tested in a specific device at Cadarache.

- In the field "***Magnets***", Euratom-CEA Association was involved to provide input information for establishing the final dimension details of the ITER cryoplant. The Euratom-CEA Association is also involved with the design of different parts of the ITER magnet system: thermohydraulic properties of cable-in-conduit conductors with a central channel, design and fabrication of mock-ups for some critical parts of the ITER coils (He inlet), tests of 'high performance' Nb_3Sn superconducting strands, joints development.

- The Field "***Tritium Breeding and Materials***" includes for a large part reactor relevant activities. Within the frame of test breeding module (TBM), activities mainly concerned the improvement and completion of the TBM engineering design. After a first design step in which the main structure, its functional features, its mounting sequence and manufacturing characteristics were defined, the second step, relied on the optimization of the design and manufacturing of the module as well as its integration to the supporting frame. A planning and list of test requirements for the qualification of the HCLL TBM was defined. A preliminary testing programme for the HCLL TBMs in ITER has been proposed on the basis of the foreseen ITER scenario and of the TBM testing strategy and mock-ups test objectives. Manufacturing of relevant mock-ups are under progress.
  Within the frame of the Helium Cooled Pebble Bed (HCPB) concept programmes, studies about the development of Li_2TiO_3 pebbles are on going. A new batch of 1 kilogram of pebbles with the size distribution in the range 0.6 to 0.8 mm was produced in 2004. The characteristics of pebbles are in agreement with the specifications for the Li_2TiO_3 pebbles. Two kilograms of pebbles were delivered for the HE-FUS 3 mock-up tests at ENEA and one sample of optimized ^6Li enriched Li_2TiO_3 pebbles was delivered for the irradiation experiment at NRG.
  Euratom-CEA has a significant involvement in the development of structural materials for a fusion reactor, mainly focused in Europe on the EUROFER, a reduced activation martensitic steel. The irradiation behaviour of this alloy at high doses and for irradiation temperatures lower than 400°C is performed in irradiation experiments conducted in the BOR60 reactor of the Russian Research Institute of Atomic Reactors. As expected, all materials harden during irradiation, but RAFM steels and in particular EUROFER 97, present the lower level of hardening and the higher ductility compared to

conventional 9Cr1Mo steels. ODS-Fe-14%Cr-Y_2O_3 ferritic alloy, having a fine grain structure, display also an interesting behaviour as RAFM steels. Euratom-CEA Association is also involving in the modelling irradiation effects programme by providing a database of Ab-initio defect energy calculations in the Fe-He system.

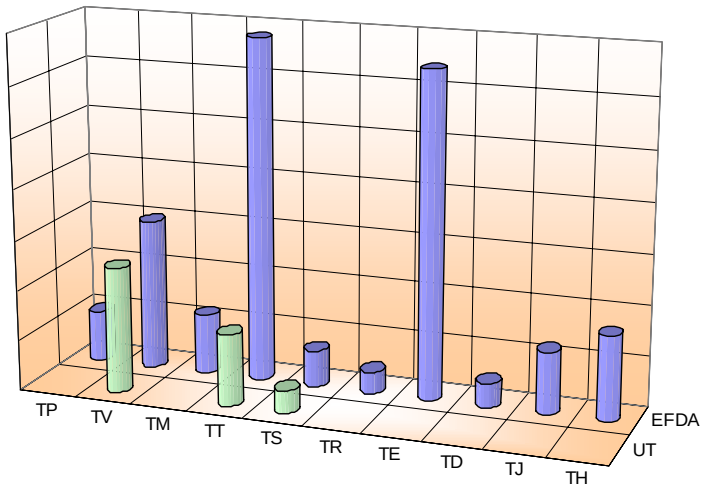
- "***Safety and Environment***" studies realized by Euratom-CEA cover different parts of this topic such as code validation experiment. The PACTITER code, an adaptation of the PACTOLE code developed for Pressurized Water Reactor, has been used for predicting the Activated Corrosion Products activities in the various Primary Heat Transfer Systems or Tokamak Water Cooling Systems (TWCS). A new tests campaign has been performed in 2004 in the new CORELE-2 loop to determine release rates of 316L under ITER TCWS operating conditions.

- Activities performed in the field "***System studies***" are dedicated to the Power Plant Conceptual Studies (PPCS). In 2004, activities were focused on the reactor model AB, based on a Helium-Cooled Lithium-Lead (HCLL) blanket. The model AB reactor is a suitable near term fusion power reactor able to supply 1.5 GWe to the grid with a gross efficiency of near 44%. Because of the high pumping power required by He-cooled systems, the net efficiency is reduced to about 35%. The HCLL blanket allows to achieve a TBR of 1.13.

- Activities carried out in the Field "***JET technology***" are devoted to the study of different processes which can be used for tritium removal from carbon materials, "Housekeeping" materials, vacuum oil and organic liquids. 2004 activities have also been devoted to the plasma facing components thermo-mechanical modelling, and to the JET diagnostics and divertor enhancement.

Three specific operational divisions of the CEA, located on four sites (see appendix 5), are involved in the Euratom-CEA fusion activities:

- the Nuclear Energy Division (DEN) , for In-vessel component design (first wall, divertor, blanket, …), neutronics, structural materials and safety activities,
- the Technology Research Division (DRT), for activities dedicated to materials (elaboration, breeding materials) and robotics,
- the Physical Sciences Division (DSM), which includes the Controlled Fusion Research Department (DRFC) operating Tore Supra and responsible for plasma physics, cryoplant and magnet and plasma facing component activities.



TP : Physics
TV : Vessel/In-Vessel
TM : Magnets
TT : Tritium breeding and Materials
TS : Safety and Environment
TR : System studies
TE : ITER Site Preparation
TD : Design Support and Procurement
TJ : JET Technology
TH : Heating Systems Technology Project

EFDA : European Fusion Development Agreement
UT : Underlying Technology

Figure 1 : breakdown of the work carried out by Field

The Euratom-CEA programme in Technology is also completed by specific R&D collaborations with industry in the fields of safety (Technicatome) and with the French National Centre for Scientific Research in the Plasma Facing Component activities.

Progress in fusion technology is constant over the years and this report once again highlights a number of important steps that have been accomplished in this domain. Euratom-CEA, together with other European Institutions is on the foreground of technological advances which are of prime importance for the success of the ITER construction. On the longer term, progress in technology will improve the vision of an electricity producing reactor and will increase the credibility of fusion energy as a genuine energy for the future. The authors and the editors should be commended for their dedicated contribution in making this report available.

M. CHATELIER

EUROPEAN FUSION DEVELOPMENT AGREEMENT TECHNOLOGY PROGRAMME