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COMMISSION OF THE EUROPEAN COMMUNITIES

Multiannual Programme of the Joint Research Centre 1980 - 1983

1982 Annual Status Report

Thermonuclear fusion technology

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THERMONUCLEAR FUSION TECHNOLOGY

1982

Research Staff: 60 men-year
Budget: 7.743.985 *

Projects:

— Fusion reactor studies :
conceptual design of experimental and power fusion reactors, system studies, safety and environmental analysis
— Blanket technology :
experimental investigations on first wall and blanket behaviour in reactor conditions
— Materials sorting and development :
investigations on the mechanical properties and radiation damage of material suited for fusion reactor structures
— Cyclotron operation and experiments :
operation of the cyclotron installed at Ispra for light ion simulation of radiation damage in fusion materials

* allocated

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Associate Programme Manager: P. ROCCO
Commission of the European Communities
Joint Research Centre
Ispra Establishment
I-21020 Ispra (Varese), Italy

1. INTRODUCTION

The objective of this programme is to study the technological problems related to «Post Jet» experimental machines and, in a longer range, to assess the engineering aspects of Fusion Power Reactor Plants.

This activity is carried-out in tight contact with the European Fusion Association laboratories.

According to the decision taken by the Council of Ministers on the JRC multiannual programme (1980-1983), the work performed on 1982 concerns four projects, namely:

— The Project 1: «Fusion Reactor Studies» concerns mainly the NET (Next European Torus) studies which have been continued in the framework of the European participation to INTOR (INternational TOkamak Reactor). This represents a collaborative effort among Europe, Japan, USA and USSR, under the auspices of IAEA, to design a major fusion experiment beyond the-upcoming generation of large tokamaks.

— The Project 2: «Blanket Technology» has the aim to investigate the behaviour of blanket materials in fusion conditions.

— The Project 3: «Materials Sorting and Development» has the aim to assess the mechanical properties and radiation damage of standard and advanced materials suited for structures, in particular for application as first wall of the fusion reactors.

— The Project 4: «Cyclotron Operation and Experiments» has the task to exploit a cyclotron to simulate radiation damages to materials in a fusion ambient.

2. RESULTS

Project 1: «Fusion reactor studies»

The participation to INTOR phase 2-A has been pursued. Three JRC Ispra representative are members of the European delegation at the INTOR workshop.

JRC contributions to INTOR concern the mechanical configuration of the reactor, the design of reactor's components and some safety and environmental items.
Other topical researchs are the investigations on liquid breeder-water interactions and on the fuel cycle.

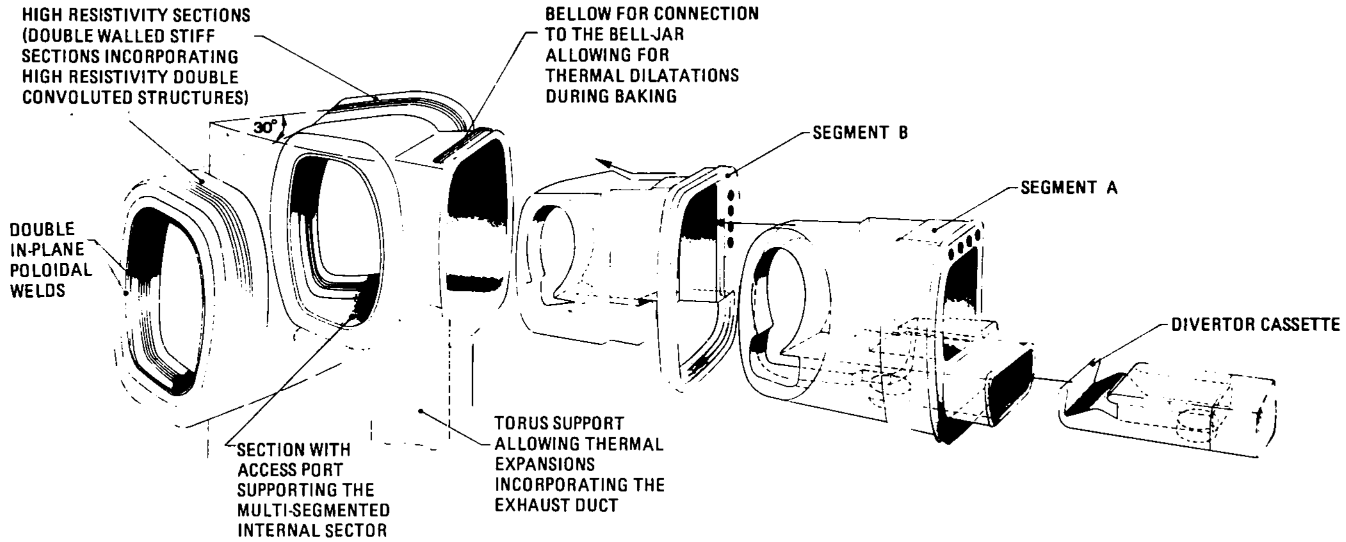

Fig. 1. Mechanical configuration of INTOR phase 2A. (European proposal)

The activity within the project is:

— INTOR mechanical configuration has been studied in more detail. It was stated that double containment inside the Toroidal Field Coils (TFC) was a proper way to detect leakages from the plasma chamber.
  Several double containment concepts have been studied accordingly, taking also into account the divergent requirements to reduce the TFC dimensions, keep an adequate structural strength of the torus and allow an easy maintenance of the renewable segments.
  The design chosen for the European contribution to INTOR phase 2-A is shown in Fig. 1.
  The semi-permanent part of the torus has 12 access ports, located between the 12 FTC. Two renewable segments of different shape pertain to each part, segment B is inserted first, with radial and diagonal movements, then segment A is inserted through the frame of segment B with a radial displacement. A divertor cassette is inserted in segment A. The two containment walls are the semi permanent part of the torus and the bell-jar (the outer wall of the cryostat) which are connected together by bellows located on the extension of the access parts.
  The study of this reference solution, with a single-null poloidal divertor has been completed with two alternative designs, each with a pumped limiter. These solutions allow some dimensional reductions of the torus and magnetic systems.
  Other assessments on the reactor's configuration concerned structural calculation of the TFC, static and buckling analysis of the bell-jar and remote maintenance-dismounting procedures.

— The development of first wall-blanket concepts has been continued. The blanket design with solid breeder (lithium oxide) and neutron multiplier (lead) has been implemented. Several designs of blanket with liquid breeder (the eutectic $Li_{17}Pb_{83}$) have been developed.
  A recent version is shown in Fig. 2, where the coolant is light water at 5 MPa with inlet-outlet temperatures of 510-530 K respectively. The first wall is cooled by H_2O (or D_2O) at 1 MPa with inlet-outlet temperatures of 320-370 K. Beside thermohydraulics, the first wall-blanket investigations concerned neutronics, neutron-induced activation and decay heat, two and three-dimensional thermomechanics with AISI-316 and ferritic steel as structural materials, tritium recovery methods from $Li_{17}Pb_{83}$.

— For the pumped limiter design (panel of tubes along the toroidal direction, water cooled) see Fig. 3, two and three dimensional thermomechanical calculations have been performed. The limiter lifetime analysis has been accomplished with the computer code SMILE, under different hypotheses of plasma disruptions and erosion, assuming fatigue and fatigue crack growth as failure mechanisms. It appears that the most important phenomenon is the behaviour of the melt layer which forms during disruptions on the limiter surface.

— Static and buckling analysis of the cryostat outer wall (bell-jar) has been performed.

— The coordination of the European contributions on INTOR safety and environmental problems has been continued. Beside JRC-Ispra, the other involved laboratories were CEA-FAR, CEA-Saclay, ECN-Petten, Risoe National Laboratory, Studsvik Energiteknik AB, Hahn-Meitner Institute-Berlin. Progress has been achieved in safety analysis methodology, first wall-blanket accident analysis, environmental effects of tritium and activated waste. Suitable ranges of values for tritium routine release to ambient and tritium concentration in the coolant have been defined.

— A computer code to assess the effects of tritium releases to atmosphere with a probabilistic methodology is under development.

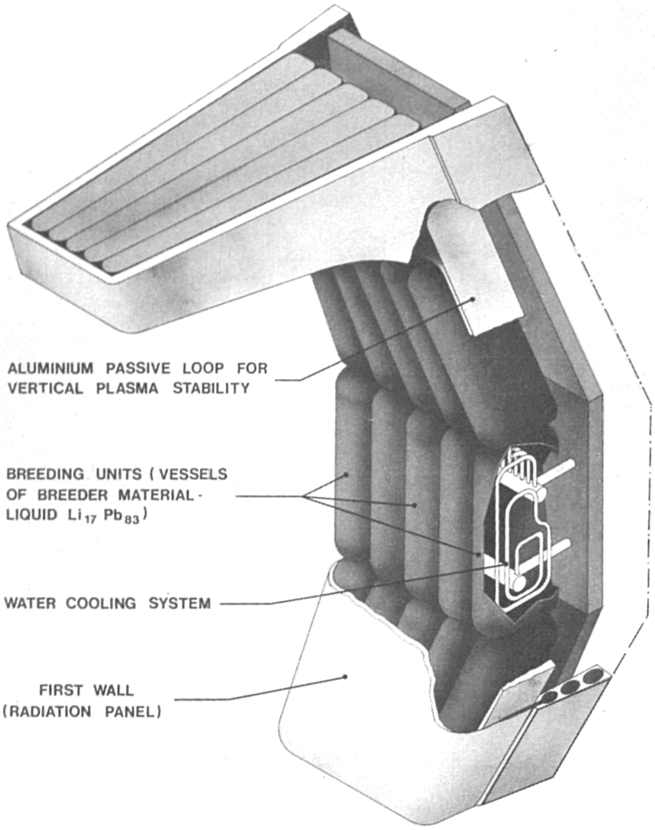

Fig. 2. Liquid breeder ($Li_{17}Pb_{83}$) blanket

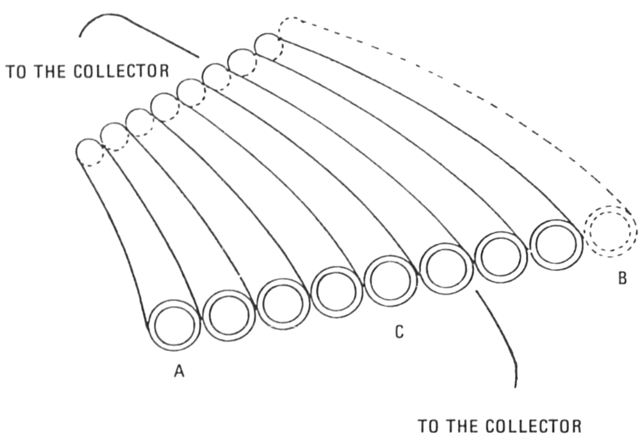

Fig. 3 Pumped limiter schematic perspective view

— Safety related experimental studies concerned liquid breeder interactions with water. Small scale tests of molten $Li_{17}Pb_{83}$ (773 K) with water (363 K) have shown a low chemical reactivity of this compound. A safety assessment at larger scale is foreseen in future.

— Two schemes for plasma reprocessing have been evaluated in alternative to cryodistillation. The plasma exhaust is oxidized and the liquid stream is electrolysed in two steps. Final separative processes are either distillation or gas-cromatography. The experimental work related to this study concerned the construction and operation of electrolytic cells with low hydrogen (H, D) inventory and high separation factors. The required voltage-current characteristics have been determined. The most suitable materials for the fabrication of electrodes have been identified.

Project 2: «Blanket technology»

The activities of this project concerned the behaviour of hydrogen isotopes in metals, basic data on $Li_{17}Pb_{83}$ and breeder-structural materials compatibility.

— The experimental research on thermal outgassing from metallic surfaces have been completed. Beside aluminium, desorption spectra and outgassing rates of Inconel 600 with different surface conditions have been investigated.

— Deuterium permeation through an AISI 316 membrane has been measured at temperatures around 580 and 700 K. These tests showed that the permeation is strongly influenced by the presence of oxidized layers and only marginally by temperature. Theoretical investigations in this field concerned the comparison between bulk diffusion and surface recombination models.

— Measurements of hydrogen solubility and diffusion in metals are prepared, based on the concept of measuring the pressure variation due to thermal outgassing of samples in a calibrated volume.

— The collection of basic data on $Li_{17}Pb_{83}$ has concerned calorimetric measurements in the temperature range of 300-573 K, as well as solubility and diffusivity of hydrogen isotopes.
These data are important to define tritium recovery methods from the breeding materials.

— The investigations on the compatibility of structural matherials with pure lithium and $Li_{17}Pb_{83}$ have been continued. Samples of different grades of Cr-Mn austenitic stainless steels (AMCR) have been heat treated in pure lithium at 837 K.
Some samples have shown a substantial grain boundary penetration, see Fig. 4.

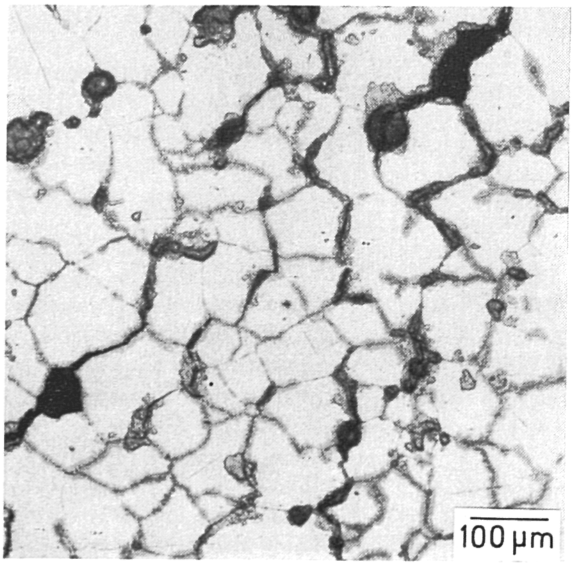

Fig. 4. AMCR steel heat treated (873 K for 1,500 h) in $Li_{17}Pb_{83}$

A sample with low N and C contents and which seems not to be fully austenitic has shown no apparent attack after more than 3,000 h of exposure.
The same grades of steels are at present investigated in $Li_{17}Pb_{83}$, taking also into account the influence of dissolved nitrogen impurity.
Other research in this field concerned the behaviour of a molybdenum coupling in presence of lithium. The results on this joint were rather satisfactory.

Project 3: «Materials sorting and development»

The main effort was devoted to the development of simulation and modelling techniques appropriate to first wall materials investigations. In particular AISI-316 and Cr-Mn austenitic stainless steels have been studied. Other researchs concerned the behaviour of protective materials for coatings and armours.

— The European reference stock of AISI-316L has been received from Creusot-Loire and distributed to different laboratories.
The mechanical characterization tests are in progress.

— The thermal stability and thermomechanical behaviour of several Cr-Mn austenitic stainless steels is under investigation. Different samples have been cold rolled at 293 K and subsequently annealed up to 873 K in a controlled atmosphere. Other samples were tested in tension up to 1,073 K. The different defect structures produced in the samples were studied by transmission electron microscopy, electron diffraction, X-ray microanalysis and electron energy loss spectrometry.

— Thermal and mechanical phase stability of Fe-Cr-Mn alloys at low C content has been studied. Previous investigations performed during 1980 were based on measurements of lattice parameters, electrical resistivity, stored energy, magnetic susceptibility, Vickers hardness and by observations at the electron microscope. They showed that the austenitic matrix contained other phases, as a consequence of plastic deformation and/or thermal treatment.
New results have been obtained by X-ray diffraction and by extended X-ray absorption fine structure (EXAFS) on samples of alloys annealed in different conditions. It was shown that plastic deformation and annealing temperature determine the final structure of the samples. Intermediate metastable phases were found, which can strongly influence the mechanical properties.

— An experimental investigation has been made on the techniques to bond protective plates (W) to the heat sink (Cu) in an INTOR divertor design. Among the three different type of bonding, i.e. diffusion bonding, brazing under vacuum and direct casting of Cu on W, the last is the most economical and relatively easy to be done. Its resistance to thermal cycling loads look promising, as can be noted in Fig. 5.

— A laboratory scale facility to investigate the thermal fatigue of the first wall and divertor/limiter under large heat flux (up to 0.50 MW/m^2) is now in operation. Tests can be carried-out in a vacuum or inert gas environment. The experimental techniques and instrumentation are being set-up. The first measurements will be devoted to study the structural integrity of AISI-316 under operating conditions corresponding to a maximum lifetime of 10^5 cycles.

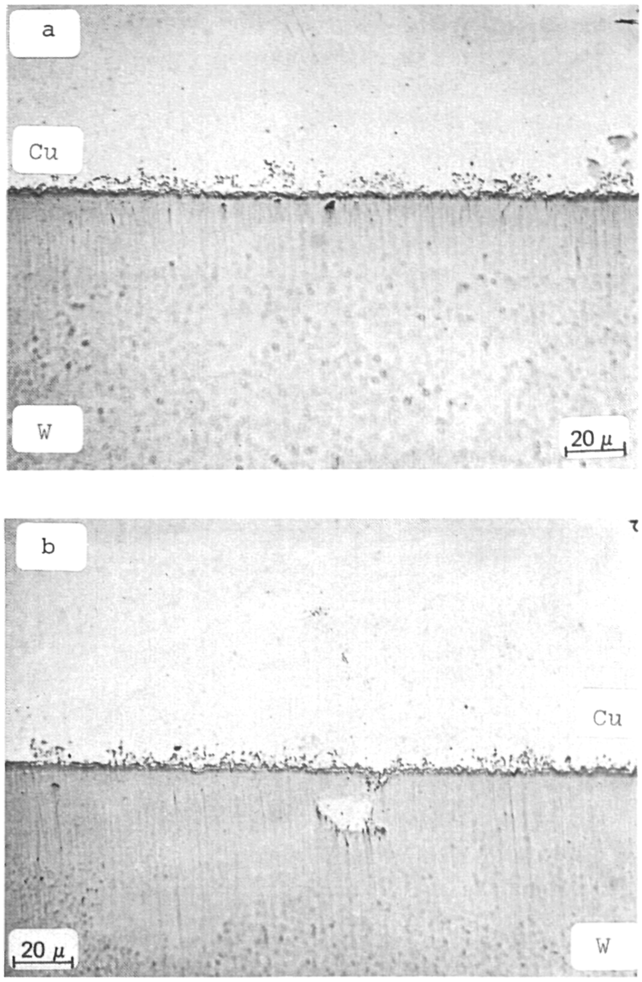

Fig. 5. Optical micrographs of Cu casting on Ni-coated W joint
a) before cycling b) after 10^4 cycles

— Assessments of the mechanical properties of Mn-Cr austenitic stainless steels under neutron irradiation are in course at the HFR reactor in collaboration with JRC Petten. The irradiation programme TRIESTE, which is at present in pile concerns about 150 samples, irradiated at temperatures up to 673 K, under tensile stress between 30 and 300 MPa.
The fast neutron fluence is up to 10^{21} n/cm^2 and creep-strain measurements are made out of pile at intervals during the reactor's shut down.
The irradiation programme FRUST, which is in preparation, concerns tensile post irradiation tests.
The specimens will be irradiated to 1; 5 and 10 dpa at 623 and 823 K. Some AISI-316 L specimens will be also irradiated at 523 K.
Another irradiation programme, CRISP, which concerns in pile irradiation creep tests is also foreseen.

— In the area of radiation damage modelling the following work was accomplished:

- The collaboration with the theoretical division of Harwell concerns appropriate developments to the rate theory of radiation damage.
- The theoretical studies carried out at JRC concern the following main topics:
  a) The physico-mathematical aspects of the problems inherent to the evaluation of characteristic parameters of the rate equations, such as sink strengths.
  b) The prediction of the swelling of M316 steel under heavy ion and neutron irradiation after a calibration of the model using electron damage data.
  c) Studies on the shrinking of voids near a free surface.
  d) Assessment of the validity and the efficiency of available computer codes for dpa calculations. In particular a critical examination is carried out of the physical assumptions, such as:
     - primary knock-on atom energy spectrum.
     - energy losses in excitation and ionization of electrons.
     - cascade development and collapse.

— The exploratory studies on an intense neutron source apt to simulate fusion spectra have been continued. A programme has been agreed upon with SIN-Villigen concerning the development of a spallation or a fission neutron-boosted spallation source.

The design of a water-centrifuge simulating the cooling of high power Li-target has been terminated and it will be operational next year.
An exchange of information has been started with LAMPF (Los Alamos laboratory) concerning the development of a rotating target beam stop.
In the same laboratory, radiation damage experiments in a spallation neutron spectrum will be performed.
Experiments on α-particles stopping power in aluminium have been terminated.
Neutron yield and stopping power of high-energy deuterons are studied in collaboration with KFK Karlsruhe.
The collaboration with Rutherford Laboratory for the installation of a general purpose neutron scattering spectrometer is going on.
Cross section calculations are performed under contract with the university of Vienna.

Project 4: «Cyclotron operation and experiments»

Cyclotron operation

Tests at maximum energy (38 MeV protons and α, 19 MeV deuterons) and maximum current (65 μA) on the three completed beam lines were succesfully performed and the cyclontron was officially accepted from the construction firm on January 29th, 1982.
Figs. 6 and 7 show the cyclotron and the beam lines.
Some minor faults to the electronic and ancillary equipment have been repaired. An accident to a turbomolecular pump re-

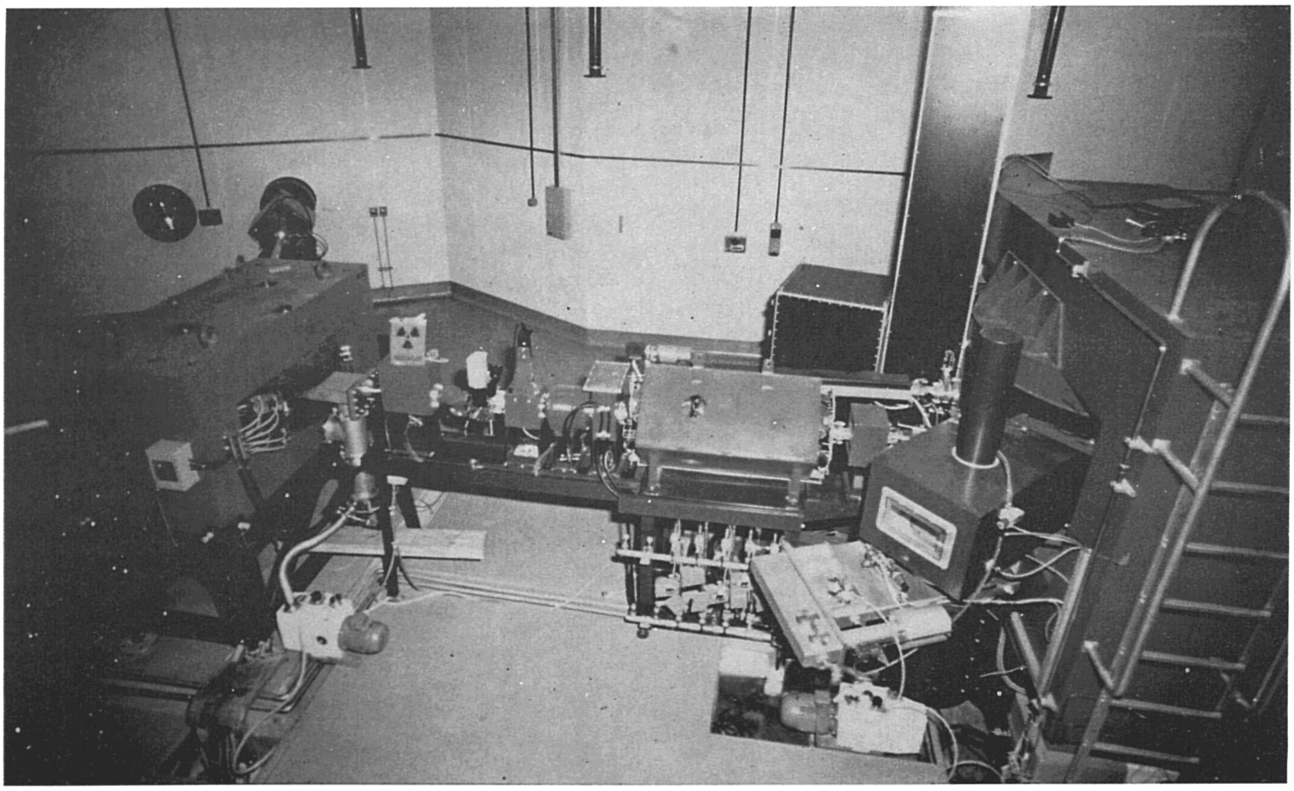

Fig. 6. The cyclotron and the beam lines

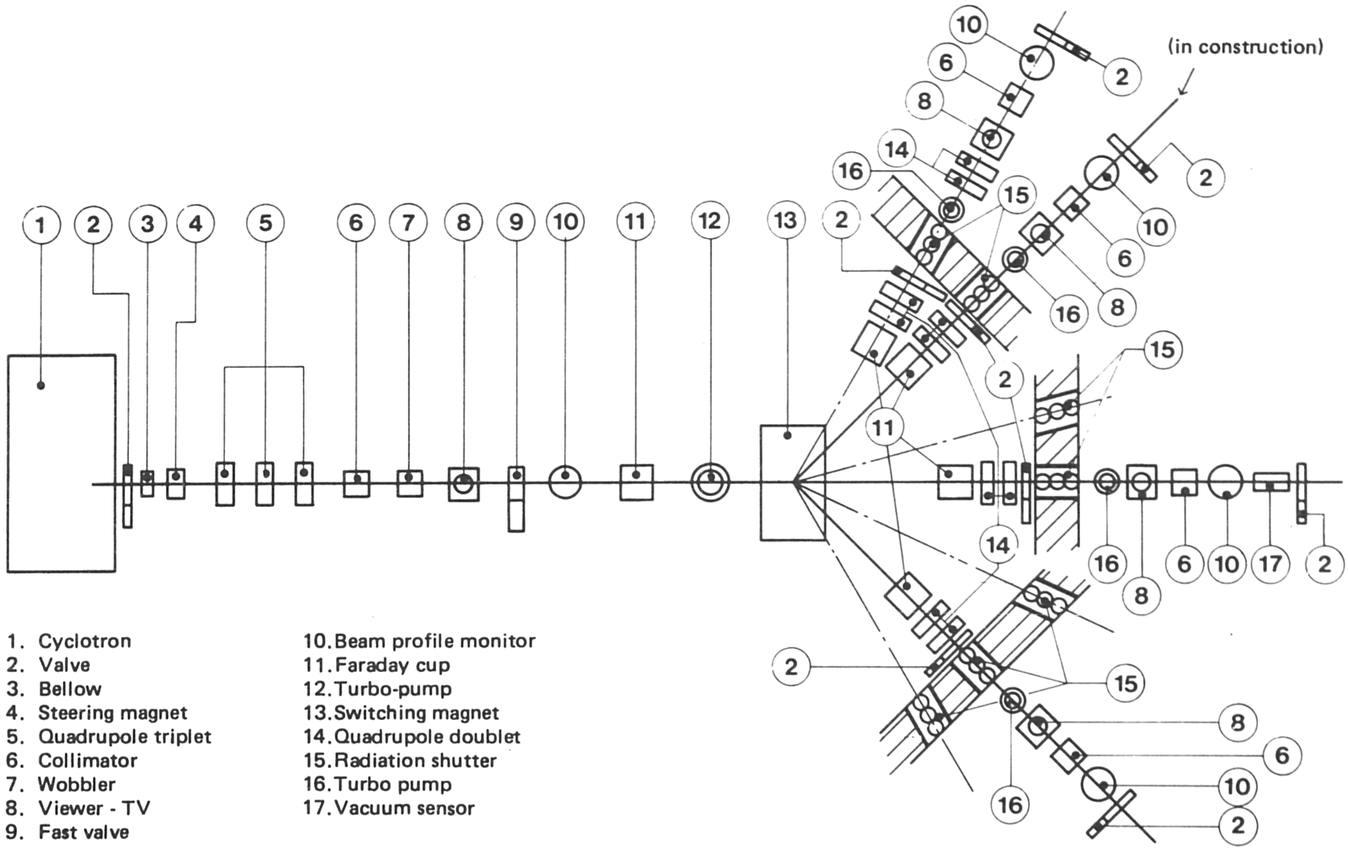

Fig. 7. The cyclotron and the beam lines

quired the substitution of both pumps and caused some delay in the experimental programme.

A liquid nitrogen supply line and a helium cooling system for the experimental facilities have been installed.

It is foreseen to have four beam lines fully equipped for the next June. Another line is being equipped for radioisotope production.

The tests requested by the Italian Authorities to grant the final license for operation have been completed (October 1982).

The cyclotron laboratory fulfils the safety requirements.

Cyclotron experiments

Aim of these experiments is the simulation of the radiation damage in fusion ambient. Other information on the four experiments prepared by JRC Ispra and described hereunder has already been given in the 1981 Annual Status Report.

The cyclotron can be used free of charge by the European Fusion Association laboratories and two new experiments are foreseen in this frame. (See: Conclusions).

Activation and gas production

The short and medium term programme is the determination of the neutron induced activation and the helium formation in materials like austenitic steels (AISI-316 and AMCR) and several aluminium alloys. The irradiation facility is almost entirely in Al-Mg alloy to reduce activation.

Work performed has concerned the improvement of the outgassing to prevent contamination of the lithium target, the setting-up of an optical autocollimation method for the alignment if all components, the rearrangement of the experimental lay-out for a better focussing of the proton beam on the lithium target.

A number of software computer programmes for the data acquisition have been elaborated and tested.

Phase stability and mechanical testing

The ultra-high vacuum assembly to perform this experiment has already been installed in the cyclotron laboratory. A new target holder to minimize handling problems has been installed. A refrigerated recirculating heat exchanger has been tested.

Irradiation fatigue

The irradiation chamber, constructed in aluminium alloy to minimize activation has been delivered as weel as other components of the experimental device. The mounting on the cyclontron line has been started.

Torsional creep

The assembling of the experimental set-up has been completed and the first creep tests under laboratory conditions have been performed. As a result of these tests the torquing mechanism and the temperature regulation are under modification.

3. CONCLUSIONS

In the project 1: «Fusion reactor studies» the design team concerned with the INTOR assessment has developed new interesting reactor configurations, gaining an experience in this field which is unique in Europe. This work can be an effective starting point for the definition of the NET design.

Progress has been achieved in blanket design, in particular for the liquid breeder ($Li_{17}Pb_{83}$) blanket.

The investigations on the pumped limiter look worth of funther development.

Safety and environmental studies, performed in collaboration with European Fusion Association laboratories have marked progress in several topics and served as a basis for the definition of the activities to be accomplished in the next years in the frame of the European Fusion Technology Programme.

The assessment of the plasma reprocessing methods produced interesting results which will be further controlled experimentally.

The main collaborations within this project are with the following organisations:

— KFK Karlsruhe: toroidal and poloidal field coils design.
— NIRA-Genova (collaboration contract): structural and vibrational analysis.
— TNO-Apeldoorn (study contract): thermohydraulics calculations and design of the divertor and limiter collector plates.
— University of Napoli: electromagnetics calculations.
— University of Braunschweig: analysis of the induced currents inside the TF coils and their supporting structure.
— Gradel S.A. Luxembourg: assembly-disassembly and maintenance procedures.
— ARTE-Bologna (study contract): stress analysis of breding blanket components.
— MATEC-Milano (study contract): stress analysis of reactor components.
— Important collaborations are also in progress with the main Plasma Physics European Laboratories, in particular with:
  - IPP-Garching
  - UKAEA-Culham
  - CEA-FAR

The main collaborations in the NET/INTOR safety and environmental studies are with ECN-Petten, Risoe Laboratory, Hahn-Meitner Institut-Berlin, Studsvik Energiteknik AB, CEA-FAR, CEA-Saclay.

— The experiences on lithium and lithium alloy reactivity foresee a collaboration with KFK Karlsruhe and ENEA (CNEN) Bologna.
— Tritium releases distribution and effects to the environment are studied under contract with CRITA, Pisa.
— Some aspects of the exhaust fuel processing are studied in collaboration with the Politecnico of Milano.

In the project 2: «Blanket technology» further data have been obtained on thermal outgassing behaviour of different materials and on hydrogen isotopes permeation in metals. The new data on hydrogen isotopes diffusivity and solubility in $Li_{17}Pb_{83}$ allow the choice of proper methods for the tritium recovery from the breeding blanket.

The assessment on liquid breeder (Li and $Li_{17}Pb_{83}$) compatibility with metals has been continued, in order to furnish further information to the breeding blanket design.

The collaborations within this projects are:

— KFA-Jülich: control of hydrogen isotopes permeation in structural materials.
— University of Cagliari (study contract): hydrogen solubility and diffusivity in $Li_{17}Pb_{83}$.
— TNO-Apeldoorn: tightness to Lithium of Mo-joints.
— Contacts are in progress with CEA-FAR for a collaboration in the study of $Li_{17}Pb_{83}$ compatibility with structural materials.

In the project 3: «Materials sorting and development» the assessment on the austenitic steels (AISI-316 and Cr-Mn) has marked progress expecially with regard to thermal stability and thermomechanical behaviour.

Additional data will be collected with the fission neutron irradiation which are in course or foreseen.

Efficient bonding techniques for divertor/limiter applications have been developed.

The new facility to investigate thermal fatigue effects is a useful tool for lifetime analysis.

Progresses have also been achieved in the theoretical interpretation of radiation damage and in the definition of a neutron source apt to simulate fusion reactor conditions.

The main collaborations within this project are:

— ENEA Frascati and IPP Garching: coatings for divertor applications.
— University of Firenze and NIRA Genova: thermal fatigue on divertor/limiter structures.
— INFN-Frascati: EXAFS measurements.
— AERE-Harwell (collaboration contract): radiation damage modelling.
— Neutron source studies: the experimental research is performed in collaboration with KFK Karlsruhe and the Los Alamos National Laboratory;
  cross section calculations are performed under contract with the University of Vienna;
  dosimetric techniques are studied in collaboration with the Politecnico of Milano, PTB Braunschweig, KFK Karlsruhe, SCK/CEN-Mol and SIN-Villigen.

In the project 4: «Cyclotron operation and experiments» the cyclotron was accepted from the contruction firm and all the licensing procedures have been accomplished. Several new systems and components have been installed and improvements in performance have been attained. Three beam lines are fully equipped for experimental purpose, a fourth will be ready for mid 1983. Another beam line is prepared for radioisotopes productions.

The experimental programme has marked some delay for an accident to a turbomolecular pump and minor mishaps but most experiments are ready to start.

The collaborations within this project are:

— JRC-Ispra has received two proposals from other laboratories for experiments to be performed at the cyclotron, namely:

- Culham Laboratory and AERE-Harwell: simultaneous generation of radiation damage and measurement of electrical properties of ceramic insulators.
  According to the present schedule this experiment could begin in 1984.
- KFA-Jülich: Homogeneous helium doping of foil specimens by a particles implantation at room temperature. This experiment could begin already in 1983.

— The neutron spectrum measurement in the activation and gas production experiment will be done in collaboration with the institute «Enrico Fermi» of the Politecnico di Milano.

For further information concerning the JRC programmes, please contact the Directorate General of JRC, rue de La Loi 200, B — 1049 BRUSSELS.

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