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COMMISSION OF THE EUROPEAN COMMUNITIES

Multiannual Programme of the Joint Research Centre 1980 - 1983

1980 Annual Status Report

Thermonuclear fusion technology

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THERMONUCLEAR FUSION TECHNOLOGY 1980

Research Staff: 60 men/year
Budget: 6,559,000 ECU

Projects:

— 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
— Material sorting and development :
investigations on the mechanical properties and radiation damage of materials suited for fusion reactor structures
— Cyclotron contruction and operation :
construction and operation of the cyclotron installed at Ispra for light ion simulation of radiation damage in fusion materials

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

1. INTRODUCTION

The objective of the JRC programme is to provide a contribution on the definition and solution of the technological problems related to a "Post-Jet" type of experimental machine and, in a longer range, on the assessment of the engineering aspects of Fusion Power Reactor Plants.
This effort is carried-out in tight contact with the European Fusion Association laboratories.
According to the decisions taken by the Council of Ministers on the JRC multiannual programme (1980-83), the 1980 activity has been oriented toward four projects which cover a broad range of fields, namely:

- The Project 1: "Reactor Studies". The main effort was oriented toward the NET/INTOR studies.
  JRC Ispra is acting as reference nucleus for NET preliminary design. For the moment being this work was made in support to the European participation to INTOR. In 1980 the conceptual design of a demonstration power reactor (FINTOR-D) was also achieved.
- The Project 2: "Blanket Technology" has the aim to investigate structural materials behaviour in fusion conditions.
  Items like tritium outgassing and permeation from structurals and materials compatibility were investigated.
- The Project 3: "Material sorting and development". Its aim is to assess mechanical properties and radiation damage of standard and advanced materials suited for reactor structures.
- The Project 4: "Cyclotron construction and operation" has the task to install and exploit a cyclotron to simulate demages to materials in a fusion ambient.

2. RESULTS

Project 1: "Reactor studies"

FINTOR-D design study

FINTOR-D is defined as a full fusion plant generating electrical power to demonstrate that all the technologies required for a prototype reactor function reliably enough to promote sufficient confidence in the construction of a prototype power station.
A view of FINTOR-D plant is shown in the Figure 1.

- In the field of plasma parameters, a one dimensional transport code for cold plasma blanket analysis has been completed and runs relative to FINTOR-D parameters

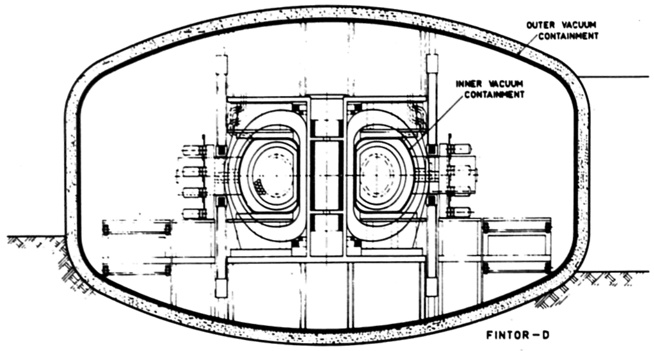

Fig. 1. FINTOR-D plant

have been performed. It was shown that the condition to get and maintain a cold plasma blanket is that the neoclassical transport dominates all the other transport mechanisms.

— Thermohydraulics of FINTOR-D have been investigated with two and three dimensional calculations by the finite elements method. The blanket units have a 520 mm diameter cylindrical shell in austenitic stainless steel, liquid lithium as breeder and helium as coolant. A protective radiation panel in front of plasma was envisaged to avoid excessive thermal stresses in the first wall. Three-dimension calculations are more realistic since they take into account the bending moments due to the non uniform heat distribution.

— The structural stability of magnet support have been analyzed with the finite element method in normal and fault conditions (failure of five coils).

— The neutron streaming in neutral beam injectors was evaluated with a MONTE CARLO calculation. It was shown that a shutter must be foreseen in the beam duct to protect the NBI cryostat after plasma ignition.

— A feasibility study for an exhaust plasma purification process have been accomplished in cooperation with SNIA-TECHNIT. After a preliminary purification on Pd-Ag membranes, the proposed method makes use of a catalytic recombiner where all the hydrogen species become the respective oxides. A coupled system of electrolitic cells and distillation column reduces the tritium inventory in the plant. This process allows small volumes and low cost. Some works are progressing to confirm the hypotheses made and a safety assessment is foreseen.

— The induced radioactivity of steel structures has been evaluated. AISI 316 and a low Ni, G-Mn austenitic stainless steels have been examined. It was shown that the higher shut-down levels of activation and decay heat pertain to AMCR. The differences between the two steels are reduced with the cooling time, then the AISI 316 values becomes predominant. These effects are due to the activity levels and decay rate of Ni and Mn activation products. No effects are expected on the maintenance possibilities caused by this different behaviour.

NET/INTOR studies

The JRC Ispra was charged to organize the European contributions to INTOR in four areas, i.e.: materials, system in-

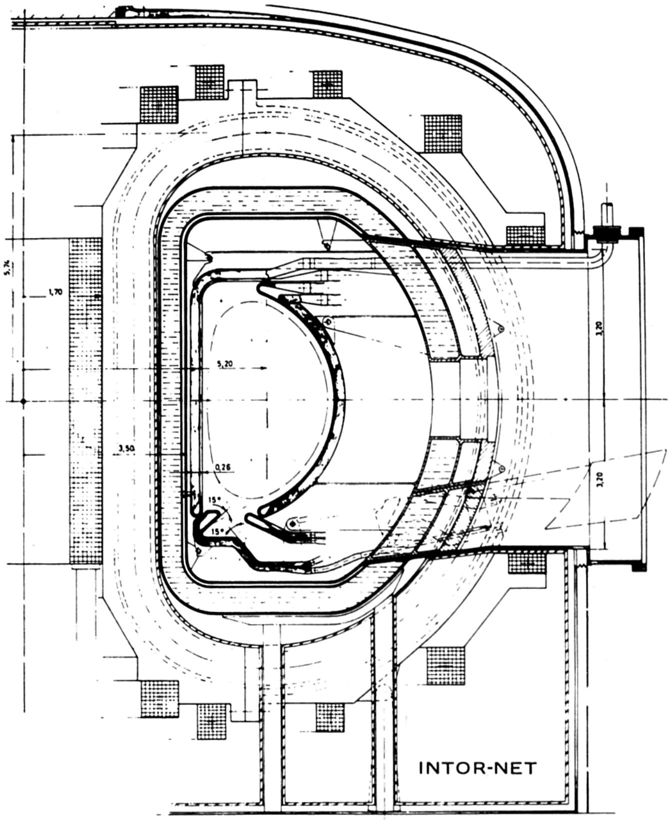

Fig. 2. INTOR/NET A2 (with divertor at bottom) - Elevation view

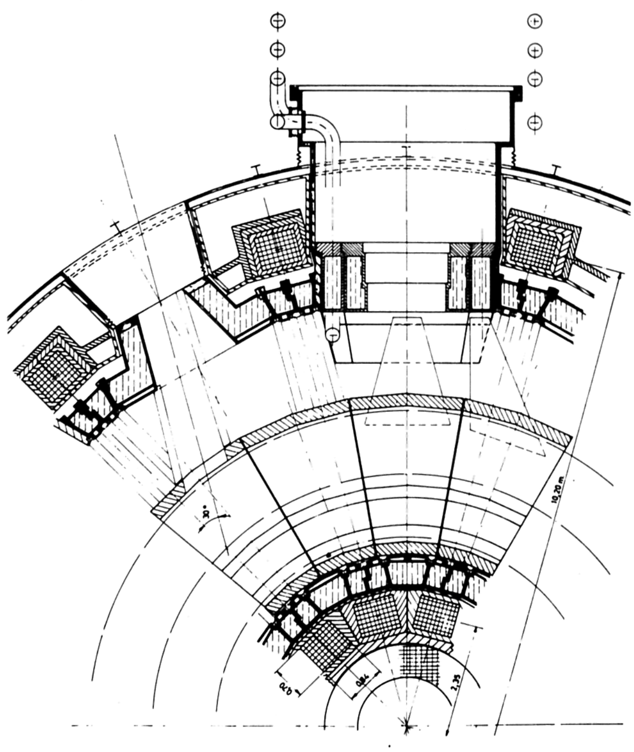

Fig. 3. INTOR/NET A2 (with divertor at bottom) - Top view

tegration and remote handling, shielding and personell access, safety and environmental problems. Contributions were also given in other areas, namely tritium, blanket and vacuum problems.

— Two different INTOR configurations have been studied, both of them allowing an easy substitution of the internals.
  In solution A1, the renewal of the internal components is carried out through 12 access ports on the top of the reactor and the number of blanket segments is 36.
  In solution A2, the renewal of the internal components is carried out horizontally through 6 access ports in the equatorial plane of the reactor and the number of blanket segments is 18.
  The configuration A2, with a single-null poloidal divertor has been assumed as reference solution for the European contribution to INTOR and it is shown in the Figures 2 and 3.
  Two containment levels are foreseen behind the blanket seguents and around the magnet system with a supplementary barrier afforded by the building.

— Two blanket concepts have been developed where a high purity aluminium alloy is used as structural material.
  In the non breeding blanket design, shown in the Figure 4, the blanket is composed of two layers mechanically and thermally separated. The first layer is actually the first wall; its thickness and design features are dictated mainly by the thermo-mechanical considerations and by the effects of plasma disruptions. H_2O is used as coolant. The evaluation of tritium permeation through the first wall showed that the periodical detritiation of cooling water can be accomplished at long instervals.
  The second concept was developed according to the INTOR-workshop recommendations on the feasibility of including a breeding blanket as a basic component for tritium production.
  Two types of breeding blankets were considered: the first uses $Li_{17}Pb_{83}$ and the second liquid Li as breeder material, respectively.

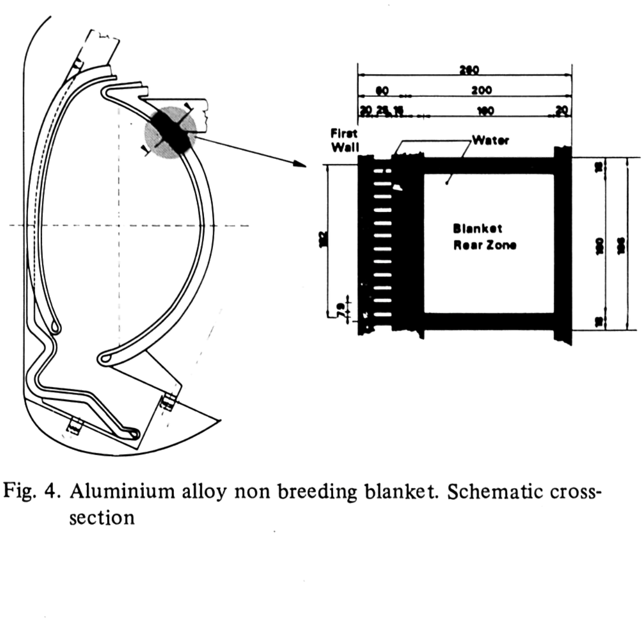

Fig. 4. Aluminium alloy non breeding blanket. Schematic cross-section

In the case of $Li_{17}Pb_{83}$ eutectic, the first wall is formed by aluminium plates containing imbedded grooves for cooling. Light or heavy water may be used as coolant. The temperature on the surface of the first wall facing the plasma can be maintained below 150 °C. The water represents a fraction of about 20% of the volume of the first wall plates. The tritium breeder material is an eutectic alloy of lithium and lead. Its melting point is situated at a temperature of 235 °C. Neutronic calculations indicated a tritium breeding ratio of about 0.75, with slightly higher values if D_2O was used in place of H_2O as first wall coolant. No direct experimental results on tritium recovery from $Li_{17}Pb_{83}$ are available. Then, it was only possible to make a first assessment based on the solubility data. On these bases, total tritium solubility in the Li-Pb blanket was found to be very low, so that tritium inventory in the blanket would be less than 100 g. Further experimental resuls are needed.

In the proposed configuration for the breeding blanket with liquid lithium, a 10 cm thick layer of lead is used as neutron multiplier. The lead is kept at a temperature low enough in order to remain in solid phase. The first wall is formed by an aluminium layer cooled by heavy water. In the breeding zone, graphite acts as moderator. Liquid lithium is contained in a double wall channel of stainless steel and is cooled by helium flowing in the annular space formed by an outer tube surrounding the lithium tube. The liquid lithium, at a temperature not exceeding 400 °C, slowly flows within the channels only for the purpose of tritium recovery. The thickness of this blanket is approximately 60 cm. From the point of view of compatibility between Li and stainless steel no major problems should arise due to the low temperature envisaged. For which concerns graphite and stainless steel, the contact temperature should not exceed 450 °C and in any case the graphite temperature will have to be kept around 600 °C. From the thermohydraulic point of view, the lattice looks quite similar to that of a graphite fission reactor (Berkeley type), so that experience and information are already available. Neutronic calculation results give slightly lower tritium breeding ratio than in the Li-Pb eutectic case. The tritium recovery from liquid lithium is carried out by a ternary mixture of LiF, LiCl, LiBr, a method which has been demonstrated feasible (A.N.L.).

— Induced radioactivity calculations showed that aluminium alloy does not present basic differences with stainless steel at shut-down and for short cooling times.
  On the contrary, after a waiting period of about two weeks the aluminium alloy offers great advantages, with simpler transfer and repair facilities than for steel.

— The safety analysis accomplished include a theoretical model for the estimation of the time-dependent electrical arc current and voltage. This model was applied to the case of arching between turns in the superconducting toroidal magnet system. The results are that the arc develops a power of several MW and can produce serious damages to magnet systems and energetic missiles.

However experimental information an arc characteristics in fusion environments must be obtained in future.

— Other safety investigations concerned a procedure to reduce tritium concentration in the plasma chamber to allow a safe opening of the vacuum zone for maintenance and an assessment on the risk related to the employ of liquid lithium as breeder.

Project 2: "Blanket technology"

— In the frame of a collaboration with the JET project, thermal outgassing properties of Inconel 600 specimens have been studied.

Measured properties:

a. thermal outgassing properties at different heating rates from 20 °C up to 550 °C.

b. decrease of outgassing rates at typical baking temperatures.

c. equilibrium outgassing rates from 20 °C up to 500 °C.

Calculated properties:

d. activation energies of desorption

e. desorption rate constants

f. equilibrium surface coverages from 20 °C up to 500 °C.

A similar set of measurements shall be executed from Al-surfaces.

The preparation of a new experimental activity has been started during this period. H_2-uptake and -release and H_2-solubility in first wall and blanket materials shall be studied in a wide range of temperature. The principle of the measuring method is the study of the weight loss in vacuum of a probe previously loaded with hydrogen. From these measurements, hydrogen solubilities and the kinetics of hydrogen uptake and release can be studied from the weight loss in function of time.

— An Ultra High Vacuum System has been installed for the determination of the diffusivity and permeability of deterium through AISI 316 membranes. The actual results on denterium permeability coefficient are comparable with reported values. A computer code has been written for the calculation of tritium loadings for vacuum vessel walls. Results have been obtained for different operating conditions and materials (NET-INTOR case).

— The compatibility lithium-structural materials has been tested on several materials. The employ of low Ni-Cr-Mn stainless steels can reduce the corrosive effects of high temperature lithium. Experiments have been carried out and are in progress to find out a corrosion resistant intermetallic surface layer in order to reduce or eliminate, if possible, the dissolution of Ni and other main components. Following American reports that the additions of 5% Al to Li seems beneficial, this possibility has been investigated on AISI 316L and Incoloy 852 samples.
Figure 5 is a S.E.M. cross section of an AISI 316L sample. Ni depletion can still be noticed, so that it is not clear whether A2 is a good diffusion barrier. Definite conclusions on the effectiveness of this protections were not yet derived and new tests are in progress.

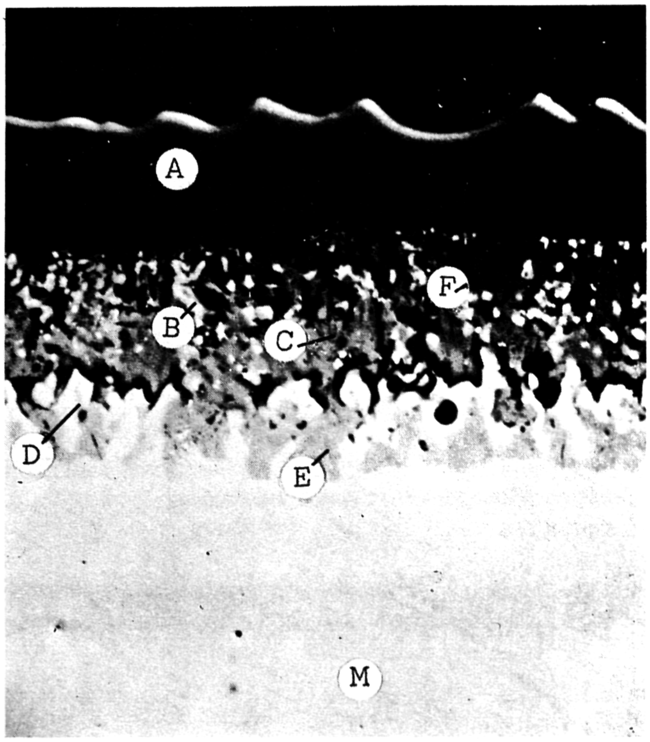

Fig. 5. AISI 316L - Li + 5% Al - 873 K - 6912 hrs.
B.E.I. composition

Tests will begin shortly to study the corrosion of AISI 316 in the $Li_{17}Pb_{83}$ eutectic.

— A computer program for lifetime evaluation of structural components of fusion reactors is in preparation. The purpose of this program is:

a. to help to solve the engineering problems arising from the conceptual reactor studies;

b. to define which are the most critical failure mechanisms and what is the minimum value of the concerned property;

c. to provide a reference procedure for evaluating the performance of widely different materials in different operating conditions.

The urgent necessity of a reference procedure and of a commonly accepted data base was brought about by the INTOR exercise, in which the different laboratories involved came sometimes to different conclusions about the estimate of the first wall lifetime in the same operating conditions and with the same material.

Project 3: "Material sorting and development"

— An Al-Mg-Si alloy has been examined as possible structural material for experimental fusion reactors. All impurities have been kept to very low levels. This alloy has been characterized (mechanical, corrosion, physical and technological properties). In particular, concerning the mechanical properties, only a slight decrease was observed in the ultimate tensile strength as compared to the commercial 6063 alloy, whereas the yield strength and elongation are very similar. Compatibility tests with water up to 4000 hours at 120 °C have shown that corrosion is very low, mainly due to formation of a protective layer of oxide.

— Embritted type AISI 316 stainless steel has been experimentally investigated with regard to mechanical anisotrophy and structural stability, mechanical behaviour, deformation and fracture modes.
  In this case very little ferrite or sigma phase was observed even after 500 hrs at 700 °C or 800 °C.

  The steel under study showed considerable anisotropy in mechanical strength and ductility, with samples taken in the rolling direction exhibiting higher strength and ductility than samples taken at right angles to the rolling direction. This anisotrophy is attributed to the observed segregation and to the non-metallic inclusions in the steel.

— Comparison studies has been initiated on AISI 316 and well characterised Cr-Mn austenitic stainless steel. In particular, in the field of radiation damage a work was accomplished on radiation-enhanced diffusion in metals. Experimental research on the recombination volumes between vacancies and self-interstitials and theoretical investigations on the kinetics of point defect reactions have been accomplished.

  A study of commercial Cr-Mn austenitic stainless steels by means of high voltage electron microscopy was made on a solution annealed AMCR steel from Creuzot-Loire with the following composition: Fe-17.5, Mn-10, Cr-0.67. Ni-0.2, C-0.06, N-0.004.
  Quantitative data have been obtained for void swelling and phase stability under irradiation between 400 °C and 600 °C, and up to doses of 40 dpa.
  It was shown that the total swelling increases with increasing radiation dose, Figure 6.

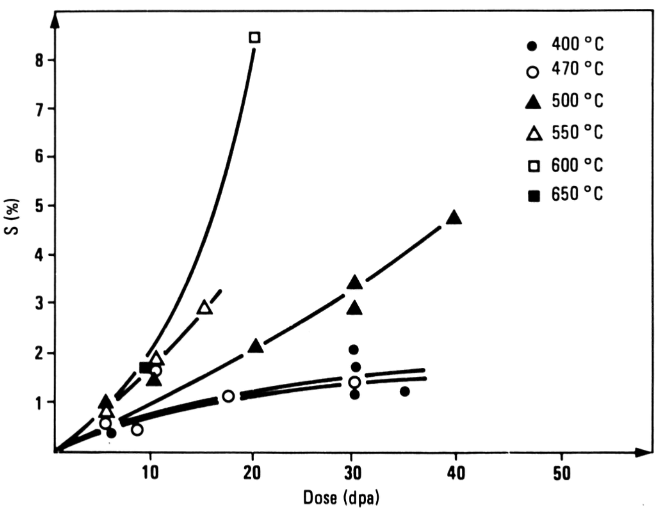

Fig. 6. Percentage void swelling as a function of irradiation dose for temperature ranging from 400 to 650 °C

  The total swelling of the AMCR steel is 20-50% lower than for a 316 SS and FV 548 SS with similar carbon contents, up to electron doses of 40 dpa at 500 °C and 600 °C.

— An experimental investigation has been accomplished to assess the validity of TiC as protection layer of the first wall.
  Titanium carbide coatings were deposited on discs of various metals (AISI 316, 310, 304, Inconel 600 and Mo).
  The deposits of TiC studied were produced by two different techniques: chemical vapour deposition (CVD) and plasma spray.
  The TiC coatings obtained with the two methods described were analysed in terms of chemical composition, structure, hardness and emissivity.
  In the case of CVD technique the Tic layers have a composition very close to stoichiometric values, as confirmed by chemical and microhardness analysis.
  Chemical analysis and x-ray difraction of TiC plasma spray coatings indicate the presence of titanium nitride and titanium monoxide (TiO) generated during coating. In some cases the oxide content up to 15 w%. The plasma spray coatings are porous.
  The adherence of the two kinds of coating were tested by thermal shock, generated by an electron beam of up to 6 kW, focused on a surface of 0.5 cm².
  The plasma sprayed coatings showed much higher termal shock resistance.

— The following tests on cyclotron (see project 4) are in preparation:

  a. An ultra-high vacuum target assembly for charged particles irradiation has been received, on the basis of a loan agreement, from JRC Petten.
     Reassembly and laboratory tests have been completed. Preparation of thin tensile and discs microsamples of low Ni, Cr-Mn austenitic stainless steel have been continued.

  b. In the same time the design of an Irradiation Fatigue Experimental System has been started.
     A prototype fatigue machine has already been constructed for crack growth experiments on thin (100 μm) specimens with pre-existing controlled defects.
     A predominantly aluminum construction was envisaged in order to minimize the activation problem.

  c. An irradiation facility has been designed for the determination of the rate of activation and gas production (He accumulation) in fusion technology materials, principally steels, by simulating the neutron irradiation conditions near the first wall and in the blanket.
     The facility allows to irradiate, simultaneously and in relatively short runs, several material samples in the close proximity of a ^{7}Li (p,n) target.
     Safety and vacuum requirements were established. As far as activation measurements are concerned, the performance of the human body counter and of other detectors were evaluated in some cases.

— An intense neutron source is under study. The neutron spectrum in the first wall of a fusion reactor is similar to

the one of a fast reactor except for a tail of fast neutrons with energies up to 14 MeV. About 30% of all neutrons are within that tail and make all the difference of fusion and fast reactor radiation damage, so that fast neutron irradiations are very important. Valuable informations can only be obtained with end of life tests, so that a neutron source with a flux of fast neutrons larger than 10^{15}n/cm^2 sec is required, in order to reach about $3 \cdot 10^{22}$n/cm^2 in one year. At the moment the solution seems to be a D-Li source, but even a spallation neutron source with a U^{235} booster is investigated.
Theoretical and experimental activities in support to this study are in progress.

Project 4: "Cyclotron construction and operation"

— By the end of January 1980, the assembly of the various parts of the MC-40 cyclotron, of the annexed electronics and of the radio-frequency system was terminated at the firm Scanditronix. The machine was then ready for the factory tests that were carried out during the months of February, March and April.

After the test, the cyclotron was disassembled and delivered at Ispra with all its ancillary equipment in two separate shipments.
Since the beginning of October all the various components of the cyclotron itself were assembled and partially tested. Alltogether the assembly of the cyclotron and related beam lines proceeds according to schedule. The entire equipment is expected to be tested with an accelerated beam by the beginning of February 1981, following some tests requested by the Italian authorities on the safety aspect of the entire installation. These tests will include the performance of the ventilation system that must meet the requirements specified in the safety reports.
A complete list of the tests to be performed is ready for submission to the licensing authorities.

The various components of the main line from the cyclotron to the switching magnet were also assembled.
Four of the seven radiation shutters to be inserted in the walls separating the cyclotron hall from the three irradiation cells were completed and installed.
Assembly of the components of the three beam lines from the switching magnet to the irradiation halls will proceed during the second half of January 1981.
Specifications concerning three types of beam line components (retractable faraday cups, beam stoppers and double slit systems) which will be common to most of the irradiation experiments around the cyclotron, were written up and discussed with various firms who are potential suppliers. A possible layout of a sophisticated helium cooling system with continuous gas purification, to be used in connection with samples that cannot be connected to a cold finger, was worked out and presented to the competent firms and to the users.
A general view of the cyclotron and beam lines is shown in Figure 7.
The concept of a standardized data acquisition and control system for the experiments was defined on the basis of the experience acquired from the European Solar Testing Installation.

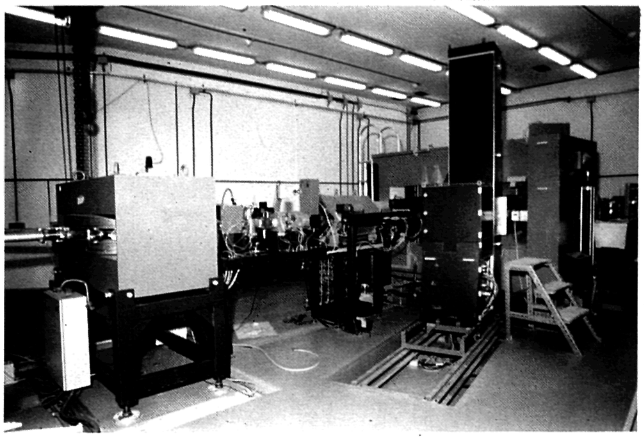

Fig. 7. Cyclotron and beam lines

3. CONCLUSIONS

In the Project 1 "Reactor studies", the FINTOR-D conceptual design study has been finished and the report is in course of issue.
This work was carried-out by JRC Ispra - in collaboration with CNEN - Frascati, FOM-Jutphaas, IPP Garching, University of Naples (FINTOR Group) and other fusion laboratories.
The FINTOR-D items investigated on 1980 were: plasma purameters, blanket thermomechanical behaviour, magnets support structural stability, neutron streaming, tritium processing and induced radioactivity of structurals.
In the area of the NET/INTOR experimental reactor studies, a reference mechanical configuration has been worked out providing a reneval of the inner zones by horizontal displacement and a multiple containment.
Non breeding and breeding blanket designs in aluminium alloy have been produced. Radioactivity problems, arcing in magnets and some other safety items have been investigated.
The NET/INTOR activity is carried out in close contact with the European Fusion Laboratories, in particular with the other European representatives at the INTOR workshop.
Two engineers, one from TNO-Apeldoorn and one from NIRA-Genova are detached at JRC-Ispra for two years to deal with divertor problems and mechanical structures of the reactor, respectively.
Collaboration on thermochemical effects due to plasma disruption is in progress with ECM-Petten, with KFK-Karisruhe and CEA-Fontenay-aux-Roses for problems related to the magnet systems.
In the field of safety, contacts are taken with Risø and Studsvik laboratories.

In the Project 2 "Blanket technology" outgassing experiments have been made in collaboration with JET. The thermal outgassing and desorption rates of Inconel 600 have been evaluated. Similar measurements for Al-surfaces are in preparation.

Experimental results on deuterium permeation through stainless steel have been obtained and calculations have been performed to evaluate tritium permeation through NET/INTOR internals. The preparation of a new experimental activity to measure hydrogen uptake, release and solubility in breeder materials have started. Long term lithium corrosion tests on steels have been performed and their analysis is in progress.
A possible protection from corrosion adding Aluminium to lithium has been evaluated. Samples of $Li_{17}Pb_{83}$ have been prepared for compatibility tests with steels.
As mentioned, the outgassing experiments are made under contract with JET. In the corrosion field exchange of information is made with CEN-Mol. Contacts have also been taken with KFA-Jülich for permeation studies.

In the Project 3 "Materials sorting and development" systematic analyses on manganese austenitic steels as structural materials are in preparation. A study of structural stability and mechanical behaviour of AISI 316 stainless steel has been completed. The possible employ of TiC layers as first wall protection has been investigated.
In the field of radiation damage a work has been performed on radiation-enhanced diffusion in metals.
A theoretical investigation on the kinetics of point defect reactions leading to macroscopic radiation damage phenonena has started in collaboration with UKAEA-Harwell.
The study of manganese austenitic steels by means of High Voltage Electron Microscope has been pursued in collaboration with SCK/CEN-Mol and the University of Antwerpen.
The design of experimental systems for irradiation and fatigue tests in the Ispra cyclotron has been pursued.
The neutron source exploratory studies are proceeding with the preparation of measurements of neutron-yield and stopping power of the D-Li reaction at the cyclotron of Karlsruhe, theoretical calculations of interaction cross sections for different materials, the construction of experimental facilities and with the preparation of sample and containers for irradiation of various material in the Los Alamos neutron source.
Collaboration is also in progress with the University of Vienna and CESNEF-Milan for foil calibration and nuclear data evaluations.

Project 4: The installation of the MC-40 cyclotron is almost completed and the basic tests will be performed during the first part of 1981 to start irradiation experiments in the second part of the year.
Contacts have been taken with KFA Jülich for various aspects related to cyclotron installation and computer control and with the Italian authorities (CNEN) for the licensing procedure.

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1980

Thermonuclear fusion technology

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