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COMMISSION OF THE EUROPEAN COMMUNITIES

Multiannual programme of the Joint Research Centre 1980-83

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THERMONUCLEAR FUSION TECHNOLOGY

1983

Research Staff: 60 men-year
Budget: 7.301.434 *

Projects:

— Fusion reactor studies :
conceptual design of experimental and power fusion reactors, system studies, safety and environmental analysis

— Blanket technology :
experimental investigations on blanket materials 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

* Commitment appropriations allocated

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Commission of the European Communities
Joint Research Centre
Ispra Establishment
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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 1983 concerns four projects, namely:

— The Project 1: «Fusion Reactor Studies» is almost entirely devoted to activities in support to NET (Next European Torus), the post-jet tokamak reactor which constitutes the main effort in Europe towards thermonuclear fusion.
In the same time, this project contributes to 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 NET/INTOR studies are strongly related, so that they have many common goals.
INTOR activities had the objective of assessing the technical feasibility of the conceptual design developed during INTOR phase 2A, part one. More precisely, this last phase looked at

the critical issues identified previously.

— The reference INTOR configuration has a single null poloidal divertor (12 divertor cassettes) 12 toroidal field coils and 24 removable segments, two for each access port of the semipermanent structure.
The engineerind design of the segments is in course at JRC Ispra, with the integration of breeding blanket concepts using the liquid eutectic 17Li83Pb and of radiofrequency auxiliary heating. Other studies concern the maintenance-refurbishing of the reactor components.

— A number of problems have been dealt with in the field of first wall and impurity control. An extensive data collection for stainless steel as firs wall material has been started.
In evaluating the thermomechanical effects on the first wall of a plasma disruption, preliminary experimental results indicate the importance to consider also crack formation in the melted and highely heated zones, the melt layer motion and the formation of helium bubbles in materials exposed to 14 MeV neutrons before the disruptions.

— The NET studies derived many inputs from the INTOR assessment. However emphasis is given to some peculiar characteristics which reflect European requirements. New sets of physical and engineering parameters are under definition and the reactor's design will evolve accordingly. The actual areas of investigations at JRC Ispra deal with some revisions of the design options. In particular:
- Improve the tritium breeding ratio from 0.6 of INTOR to values approaching unity. To achieve this objective, NET should have a breeding blanket also in the imboard region of the plasma chamber.
- Consider the removal of the internals from the top of the reactor and compare with the solution involving horizontal radial movements.
- Investigate the advantages and disadvantages of a fully remote maintenance.
- A symmetric configuration of the poloidal field coils, with the plasma centered on the equatorial plane and designs with a pumped limiter for impurity control have been also investigated.

— In the area of reactor components a tubular first wall concept, already presented at INTOR phase 2A, has been developed.
Most evaluations consider water as coolant but also helium has been preliminary considered. Beside 3-D thermomechanical calculations, this first wall has been assessed with regard to electromagnetic forces due to plasma disruptions.
The breeding blanket design using 17Li83Pb has been modified in order to be compatible with the stabilizing rods. In the new configuration the blanket modules are cylindrical and arranged in a poloidal direction.
Beside a better resistance to accidental conditions this configuration is extrapolable to more advanced operating conditions.
In the attempt to increase the tritium breeding ratio an inboard breeding blanket with 17Li83Pb is also under investigation and a possible solution is shown in Fig. 1.

— Tritium recovery methods from 17Li83Pb have been analysed. The two schemes investigated are:
a) direct pumping of tritium above the melt;
b) countercurrent helium flushing through a packed chemical reactor.

Method a) looks feasible only in case of perfect stirring of the liquid breeder, which can be realized only outside of the blanket units.
Method b) looks attractive, provided that low tritium inventory can be maintained with acceptable dimensions of the packed reactor and helium flow rates.
An experimental facility to test with hydrogen these methods of recovery is under development (within the activities of Project 2 «Blanket Technology»).

— An evaluation of the procedures and times needed to exchange the reactor renewable internals has been made. Typical times for the substitution of a divertor cassette are about 3 days, whereas for a blanket segment they are of the order of 5 days. All these operations require the use of a transfer flask.

— The activity in nucleonics consisted mainly in up-dated calculations of NET/INTOR inward shield, taking into account discontinuites and shield reduction due to the presence of breeding modules and current breakers. Additional shielding thicknesses must be of 5-8 cm.
A new computer code ANITA for neutron-induced radioactivity calculations, is under developement.

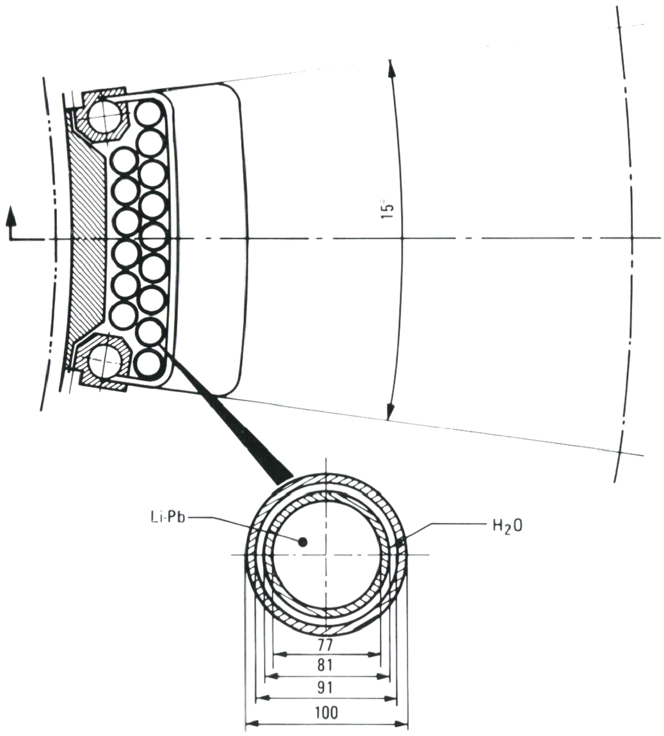

Fig. 1. Inboard breeding blanket

— The coordination of the European contributions to NET/INTOR safety and environment problems has been continued. Topics studied directly by JRC Ispra included:
  - Effects of oxidized tritium releases to atmosphere, assigning ranges of incertitudes to the main physical and meteorological parameters.
    It was shown the strong influence of the meteorological conditions. The probabilistic computer code ZEPHYRO used for these calculations is under modification, to take into account other computational models, like tritium atmosphere and soil bacterial oxidation.
  - 17Li83Pb chemical reactivity experiments. Spray tests in air and water of the eutectic at temperatures up to 773 K and pressurized water (up to 25 bar) and injection tests in the molten alloy showed a scarce reactivity.
  - Assessment of a loss of coolant accident due to a water tube break in a blanket modulus. The calculations were performed with the finite elements technique. It was shown the necessity to evaluate pressure transients effects on the wall by dynamic calculations, assuming an elasto-plastic behaviour of the structure.

— The non-radioactive tests on a low liquid inventory electrolytic cell for hydrogen isotopes separation has been continued. Separation factors between protium and deuterium were very good. Experiments are foreseen on cell's diaphragms to assess the resistance to radiation damage and on characterization of suitable electrodes and electrolysers.

— The «IAEA Technical Committee on Environmental and Safety Aspects of Fusion» was held at JRC Ispra on 17-21 October 1983. Ispra contributions concerned:
  - Problems raised by neutron activation;
  - 17Li83Pb chemical reactivity with air and water;
  - Analysis of a loss of coolant accident in a blanket modulus;
  - Biological effects of tritiated compounds.

Project 2: «Blanket technology»

The activities within this project concerned the behaviour of hydrogen isotopes in metals, basic data on 17Li83Pb and breeder-structural materials compatibility.

— Experimental studies are in course to assess the hydrogen isotopes solubility, diffusion and permeation in structural materials.
  A facility to assess deuterium permeation through stainless steel membranes in presence of 17Li83Pb has been completed, but measurements have been delayed due to some defects in the experimental apparatus.
  Another facility has been developed for accurately measuring the very low diffusivity and solubility of protium and deuterium in first wall, limiter and divertor candidate materials.
  First measurements concerned the system deuterium - Inconel 625 in the temperature range 650-900 K and pressures from 0.01 to 1 bar. The results showed the validity of the Sievert's law in the pressure range investigated and were in agreement with measurements performed in other laboratories.

— Former results of hydrogen solubility measurements in 17Li83Pb showed the need of additional data in the pressure range 0.1-1000 mbar for temperatures up to 1000 K and the activity was oriented towards this taks.
  Preliminary measurements performed in a new installation below and above the melting point of 17Li83Pb showed reproducible results.
  Other investigated parameters were the 17Li83Pb evaporation and effusion rates.

— The experimental facility under development to test tritium recovery methods (see also Project 1 «Fusion Reactor Studies») will investigate the following items:
  - kinetics of hydrogen desorption rate in static and dinamic presence of helium;
  - hydrogen recovery by direct pumping from the blanket.
  - hydrogen recovery from the blanket using a countercurrent helium stream or by pumping under vacuum in a separator.

— A 10 kg batch of 17Li83Pb has been prepared at JRC-Geel and will be delivered to European laboratories in order to perform measurements on a homogeneous material.

— Reactivity tests of 17Li83Pb at 573 K with traces of water vapour have shown strong lithium depletion and the formation of lithium hydroxide.

— Compatibility static tests of 17Li83Pb with AISI 316L in presence of oxygen and nitrogen have been completed. It was shown that nitrogen is not a corrosive impurity as the corrosion process does not differ from that of the pure alloy. Conversely, tests performed in presence of oxygen showed enhanced corrosion effects. Fig. 2 depicts an AISI-316L sample.

— Preliminary tests on liquid metal embrittlement effects are in progress.

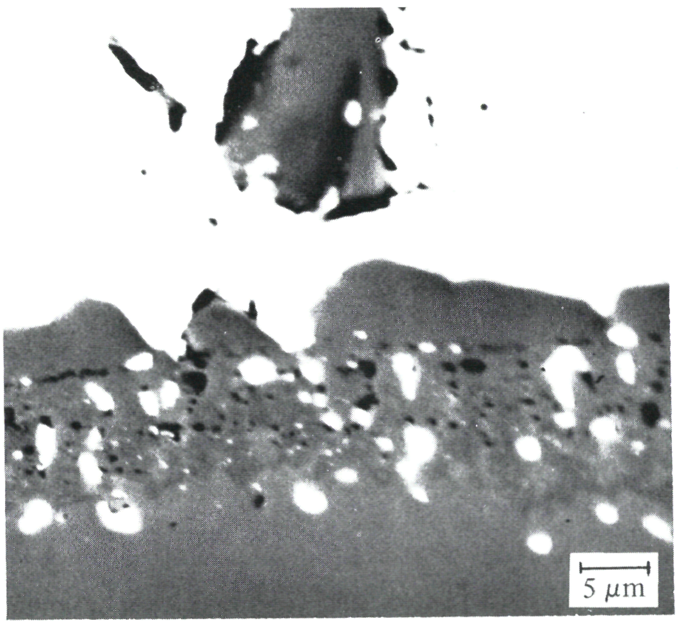

Fig. 2. S.E.M. micrograph of AISI 316L heat treated at 873K for 500 h in 17Li83Pb under flowing A + 5% O2

Project 3: «Materials sorting and development»

The main effort of this project is the selection of materials appropriate for first wall and blanket structures, which are assessed with simulation and modeling techniques to reproduce fusion environment.
Other research concern protective coatings and armours.

— Mn-Cr austenitic stainless steels (AMCR series) were characterized with tensile tests in the temperature range 300-1300 K, at different strain rates. For most tensile properties, a structural change or different deformation mechanism is active up to 500 K; in the range 500-900 K a certain stability is present, whereas for higher temperatures other structural changes are present. Lower deformation speeds result in lower stresses. Higher Mn and Cr content result in lower stress and higher strain values.
Other characterization analyses included phase stability during thermal ageing, deformation-induced phase creep tests and assessment of deformation in martensitic phases.

— Work is also in progress to assess the phase stability under irradiation of austenitic steels from the variation in electrical resistivity in function of temperature.

— In the field of materials research for divertor/limiter applications, Cu-W joints obtained with different techniques have been subjected to characterization tests to establish the nature of the joint, its development during different thermal treatments and the behaviour under thermal cycling. Fig. 3 shows thermal cycling effects on a braised joint. The most promising joints were obtained by melting copper on nickel-coated tungsten. New joints of this type will be tested to high thermal loads, up to 2 MW/m².

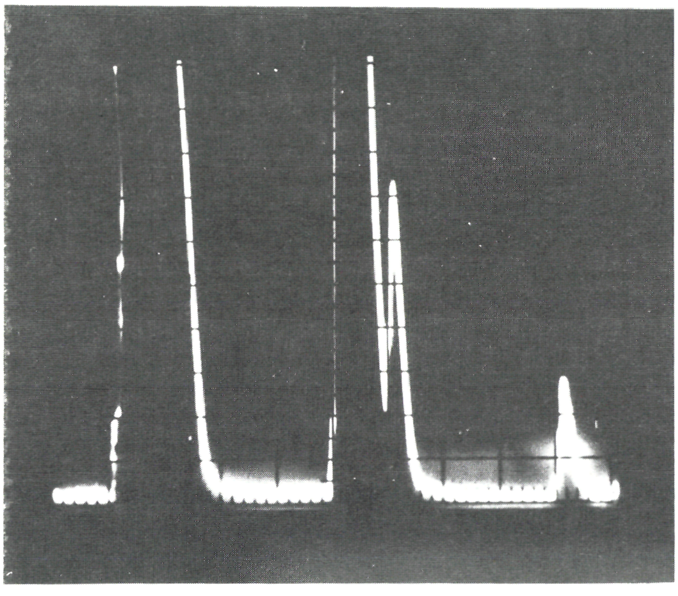

Fig. 3. Ultrasound spectrum showing a crack produced during the thermal cycling in a braised joint

— Preliminary tests of plasma disruption simulation have been accomplished. Thermal fluxes up to 10 kW/cm² are obtained by an electron beam gun. The purpose is to measure evaporations rates and melt layer stability.
AISI 316, Al, Cu, Mn and Mo specimens have been tested as well as coated structural materials, consisting of steel with TiC protective layers produced by plasma spray and chemical vapour deposition.

— The experimental programme of radiation damage on austenitic steels is in course at the JFR reactor of JRC Petten and at the MC-40 Cyclotron of JRC Ispra. Information on cyclotron irradiations is given in the project 4.
The neutron irradiations at HFR include the creep experiment TRIESTE and the post irradiation tensile tests experiment FRUST, which are in course. The creep experiment with continuous strain measurement CRISP is scheduled to start on Autumn 1984.

— Theoretical work on radiation damage modelling dealt with studies of including the effects of precipitates and solute atoms in the rate theory and comparison with experiments on the void swelling on solute-treated steels irradiated with 1 MeV electron. Other investigations concerned primary damage in steels produced by 18 MeV protons as a mean to simulate neutron damage.

— The studies on intense neutron sources for materials damage investigation in fusion ambient have been continued. Tests on the stopping power of deuterons in lithium have been completed, indicating the necessity of further tests with deuterons. Calculations have been performed on He-production and dpa of a neutron-boosted spallation source indicating that neutron spectra are comparable to that of the first wall of a fusion reactor.

Project 4: «Cyclotron operation and experiments»

Four beam lines (No. 1, 2, 4, 7) are operational and work is in progress on the line No. 6.
Beside the JRC experiments, the cyclotron is available free of charge for experiments of laboratories of the European Fusion Association.
The actual status of the experiments is as follows:

— Activation and He-production. The purpose is the determination of neutron-induced activation and He formation in austenitic steels (AISI 316 and AMCR) and aluminium alloys. The 14 MeV neutron source is realized through the reaction 7 Li (p, n). The irradiation facility is almost entirely in Al-Mg alloy to reduce activation.
The determination of neutron spectra for different energies (from 16.5 to 20.25 MeV) of the impinging protons have been completed.
Final preparation work included a rearrangement of the experimental facility to reduce spurious neutron sources and for a better focussing. Irradiation will begin in early 1984.

— Phase stability and mechanical testing. This experiment will investigate the phase stability and the variation of

mechanical properties in stainless steel microsamples under proton and alpha particle irradiation.
The irradiation chamber has been modified to improve the ion beam profile. Also this experiment will begin in early 1984.

— Irradiation fatigue. This experiment will measure crack growth propagation in notched specimens under cyclic loads and light ion irradiation.
The control instrumentation has been improved. Laboratory tests for long time operation have been performed. The irradiations are scheduled to begin in the second half of 1984.

— Torsional creep. In this experiment the creep produced by torsion on wire samples under proton irradiation will be measured by the angular deflection as a function of time. Beam tests have been accomplished to obtain a narrow beam profiles, apt to produce homogeneous damage rates. Calibration tests of the cooling system have also been performed. Irradiations are scheduled to begin on May 1984. Fig. 4 shows the experimental apparatus.

— Homogeneous He-doping (Collaboration with KFA Jülich). This experiment foresees alpha irradiation of foil specimens (AISI 316, Ni, Mo) for post-irradiation studies of mechanical properties and microstructural investigations. As mentioned previously, this is a KFA-Jülich experiment. Alpha energies were 28-38 MeV and He-implantations of 100, 150, 1000, 2000 appm were obtained. The required homogeneity was more than 90% in the horizontal and more than 80% in the vertical direction. During this experiment the cyclotron was operated for a 4 weeks period to its full extracted current capability on two shifts (16 hours) per day. The post-irradiation analyses are in course at KFA Jülich.
Other series of irradiations are foreseen on 1984.

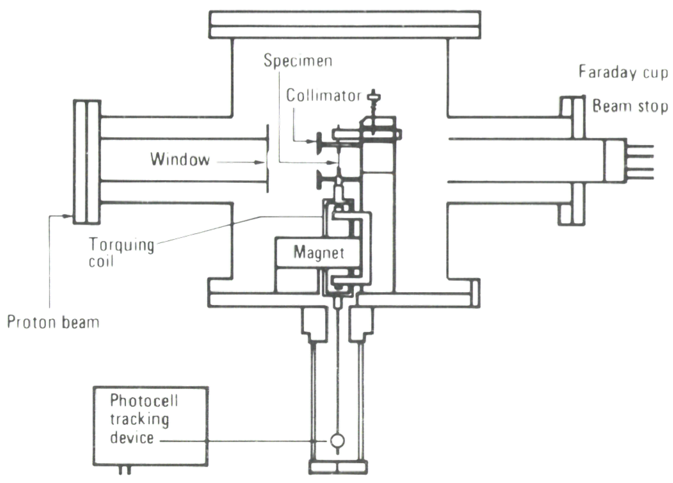

Fig. 4. Schematic illustration of the torsional creep machine

3. CONCLUSIONS

The project 1: «Fusion reactor studies» supported the NET activities. In particular, starting from the INTOR assessment, new requirements suited to European needs have been developed. Progress has been marked in the reactor configuration and related maintenance capabilities. Different solutions for some main systems have been investigated.
Safety and environmental problems have been dealt with some peculiar topics directly studied at JRC Ispra and as coordination of the work performed in other European laboratories.
The main collaborations in this project are:

— KFK Karlsruhe: in the framework of the European contributions to INTOR, the toroidal and poloidal field coils designed by KFK are integrated in the JRC Ispra mechanical configuration.
— NIRA-Genova (collaboration contract): the following topics are investigated:
  - structural analysis of the TF coils structure;
  - evaluation of mechanical stresses inside the blanket, due to the electromagnetic loads;
  - vibrational analysis of the torus system;
  - engineering feasibility study of the segments constituting the torus;
  - new first wall concepts.
— TNO-Apeldoorn (study contract): thermohydraulics calculations and design of the divertor and limiter collector plates.
— University of Napoli (collaboration contract): determination of the loads due to the induced currents inside the first wall, the blanket and the vessel segments;
— MATEC-Milano (study contract): stress analysis of reactor components;
— University of Braunschweig (study contract): analysis of the induced currents inside the TF coils and their supporting structure.
— Gradel S.A. Luxembourg (study contract): assembly-disassembly and maintenance procedures.
— ARTE-Bologna (study contract): stress analysis of breeding blanket 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 Bologna.

— The 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.

— Some feasibility studies on tritium system are performed in collaboration with SNIA - Techint Roma.

In the project 2: «Blanket technology» additional information has been obtained on the behaviour of hydrogen isotopes in structural materials and liquid breeders. Investigations on the Li-Pb eutectic have made progress.
The main collaborations are:

— Control of permeation results is made in collaboration with KFA-Jülich.
— University of Cagliari (study contract): hydrogen solubility and diffusivity in 17Li83Pb.
— Società Costruzioni Aeronautiche Giovanni Agusta (study contract): S.E.M. analysis of metallographic samples.
— Contacts are in progress with CEA-FAR for a collaboration in the study of 17Li83Pb compatibility with structural materials.

The project 3: «Materials sorting and development» has continued the characterization of Mn-Cr austenitic steels, which is almost completed with regard to out-of-pile investigations.
The research on coatings and armour has given good results for limiter/divertor applications and, more generally, for protection of plasma exposed structures. Future experiments on plasma disruptions effects will be an important tool in support to reactor design.
In the field of radiation damage, the in-pile experiments are in course at HFR Petten and the theoretical modelling has made progress, in support to the in-pile and in-beam investigations. (The last ones are presented in project 4).
Intense neutron sources studies have shown that they could reproduce adequately the fusion environment.
The main collaborations are:

— Coatings for divertor applications are studied in collaboration with ENEA Frascati and IPP Garching.
— Effects of thermal fatigue on limiter/divertor are studied experimentally in collaboration with the University of Firenze and NIRA Genova.
— EXAFS measurements are done in collaboration with INFN-Frascati.
— Radiation damage modelling is studied in collaboration with AERE-Harwell (collaboration contract).
— Neutron source studies: the experimental research is performed in collaboration with KFK Karlsruhe, the Los Alamos National Laboratory and SIN-Villigen.
  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.

Project 4: «Cyclotron operation and experiments»

Four beam lines are operational and work is progress on another one. Final fitting of auxiliary systems has been completed.
The four JRC Ispra experiments have marked some delay, mainly due to teeting troubles of the experimental facilities and non-foreseen modifications. However scientific data from all of them are expected in the course of 1984.

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

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