

**Modulo 2:**

Riferimento a linee guida	FORM N.: 5 PROGRAM EVALUATION FORM
3b.1	Nome programma: Name of the program
	FUSION
3b.2	Responsabile programma Responsible of the program
	Giorgio Rostagni
3b.3	Obiettivi specifici del programma Specific objectives of the program
	<p><b><i>Programme “fusion”</i></b></p> <p><i>Introduction</i></p> <p>In the reporting period 2001-2005, the Fusion program has been carried out by Consorzio RFX, whose partners were the University of Padova, CNR, ENEA and Acciaierie Venete S.p.A. Consorzio RFX was founded in 1996 to formalize the strict collaboration among the three research institutions, to create a single, efficient management structure and to develop the synergies which are mandatory for such a large scale research activity.</p> <p>Europe holds presently the world leadership in the field of Fusion, as evidenced by two facts. Europe has built and is operating the largest Fusion experiment over the world, JET, which showed the best fusion performance. Secondly, Europe is now starting construction of the first fusion reactor, ITER, in Cadarache (Provence), with the collaboration of United States, Japan, Russia, China, Korea, India.</p> <p>Consorzio RFX is the Padova Research Unit of the Italian Association with Euratom for fusion development. Consorzio RFX participates in the European fusion program over a wide spectrum of activities, described in the following section. Among these activities, it is worth evidencing that the group designed and built in the eighties and operates since 1992 the RFX experiment, which is one of the major European machines, financed by the European Commission for 45% of the investment costs.</p> <p>During the reporting period, Consorzio RFX had on average a manpower of about 60 (equivalent full-time) professionals, plus an equivalent number of technical and administrative staff.</p> <p>Among the professionals, the DIE contributed with 12 professors and researchers (see section 4); a very significant number of PhD students from the Electrical Engineering and Energy Research courses participated in the research. Since the research carried out by Consorzio RFX is highly interdisciplinary, the contribution of the Padova University is coordinated within an Interdepartmental Research Center “Centro Ricerche Fusione” (CRF), which involves 4 Departments of the University. The Center also provides the Technical and Administrative staff listed in section 4b.</p> <p>It is worth noting that the DIE professors played key roles in Consorzio RFX during 2001-2005:</p> <ul style="list-style-type: none"> <li>- President of Consorzio RFX</li> <li>- Director of Consorzio RFX</li> <li>- Deputy Director of Consorzio RFX</li> <li>- Director of Istituto Gas Ionizzati del CNR</li> <li>- Director of CRF</li> <li>- Responsible of the RFX machine enhancements</li> </ul> <p>The RFX research group, including personnel from Università di Padova, CNR, ENEA and direct employees of Consorzio RFX, is fully integrated in a single management structure, characterized by specific groups and lines of program: thus the research activities are</p>

	<p>organized according to competence and not to employer. For this reason, the description of this Program is necessarily referred to the whole activities of the group.</p> <p>Given the leading responsibilities of DIE professors, the share of DIE both in terms of available financial resources and of the research outcomes is certainly higher than the share resulting from a simple proportionality (on average over the period, 11 professionals of DIE/60 professionals of the group).</p> <p>On top of that, it should be evidenced that the PhD students of DIE (10 on average over the period) gave a very important contribution to the results.</p> <p><i>Specific objectives of the program "Fusion"</i></p> <p>The general objective of this program is the development of an abundant, safe and ecologically compatible primary energy source by the use of nuclear fusion reactions inside a magnetically confined plasma.</p> <p>The specific objectives of this program are the following:</p> <ul style="list-style-type: none"> <li>a) to exploit and develop the RFX experiment. RFX is a toroidal machine (major radius 2 m, minor radius 0.5, maximum plasma current 2 MA) that confines a hydrogen plasma in the Reversed Field Pinch magnetic configuration. Compared with the Tokamak configuration (which presently gives the best performance and which has been adopted both for JET and ITER), the potential advantages of the RFP configuration are the much lower magnetic field intensity and the better accessibility due to the absence of constraints about the major radius/minor radius ratio.</li> </ul> <p>During the reporting period, RFX was subject to an important enhancement (2001-2004) mainly to introduce active control of MHD instabilities by radial field coils and fast amplifiers (see Project 1) and to improve the plasma diagnostics (see Project 2).</p> <p>Since December 2004, the machine is regularly operating and in 2005 produced excellent scientific results both in terms of plasma confinement properties and in terms of instability control capabilities (see Project 3)</p> <ul style="list-style-type: none"> <li>b) to contribute to the ITER design</li> </ul> <p>The group has contributed to the European design activities in the fields of power supplies, magnetic and optical diagnostics, instability studies, plasma control and, since 2003, the group assumed the leadership in the design of the ITER Neutral Beam Injector (see Project 4)</p> <ul style="list-style-type: none"> <li>c) to contribute to JET enhancements</li> </ul> <p>The RFX group had the full responsibility of two key enhancements of JET (High resolution Thomson Scattering and Halo Current Sensors) and has been in charge of the design and construction of the new magnetic Measurements, under the coordination of CREATE (see Project 5)</p> <ul style="list-style-type: none"> <li>d) to develop specific technologies in collaboration with industry</li> </ul> <p>European leading companies were involved in the construction of RFX and of the JET components under RFX responsibility. Several spin-offs derived from this collaboration, described in Project 6.</p> <ul style="list-style-type: none"> <li>e) to train young researchers for the EU fusion program</li> </ul> <p>Owing to the direct relationship with the University of Padova, Consorzio RFX is one of the most active Fusion laboratories in this field. Besides the role in the PhD courses, evidenced in Section 4b, Consorzio RFX organizes the post-graduate, second level annual Master Course on Engineering and Physics of Plasmas (director: prof. Antonio Buffa), with 7 grants per year</p>
3b.4	<p>Progetti in corso Projects running</p>
	<p>Project 1: <b>RFX-mod</b></p> <p>The RFX experiment is in operation since 1992 and has been substantially improved in</p>

the period between 2001-2004 in order to meet new experimental goals.

A more extended description of the modifications implemented in the RFX experiment can be found in Annex 1.

#### Modification of the experimental device

The machine modifications have been oriented to improve the performance in the following areas:

- 1) to increase the first wall power handling capability
- 2) to improve the vacuum vessel wall protection
- 3) to improve the axisymmetric equilibrium control in conjunction with the reduction of the vertical field penetration time constant with the new passive shell
- 4) to minimize the magnetic field errors

Moreover the machine modification is devoted to improve and to introduce new active control of the MHD modes:

- 1) to increase the amplitude and the operational window of frequency of the torque applied to the plasma to drive plasma rotation
- 2) to actively control the magneto hydrodynamic instabilities
- 3) to minimise the radial magnetic field at the “plasma boundary”.

The following new components have been designed and installed between 2002 and 2004:

- 1) New graphite first wall
- 2) New system of internal sensors
- 3) New active/passive magnetic boundary
  - 3.1) New magnetic and thermal sensors
  - 3.2) New thin copper stabilizing shell
  - 3.3) New Stainless Steel toroidal support structure
  - 3.4) New system of 192 Active saddle coils to control MHD modes

#### New Power supplies and control systems

Contemporary to the construction and assembly of the toroidal device, a substantial improvement has been implemented to feed the new and the existing winding systems.

In particular the modifications have been devoted to increase the flexibility of the toroidal field power supply and to the realization of the power supplies for the new saddle coil system. For the 192 saddle coils, a completely new subsystem of 192 independent power supplies has been manufactured and installed.

A sophisticated real time control system able to handle a large number of inputs (few hundreds) to generate individual current (or voltage) references to each power supply (192 plus 21 for the other winding systems) with a latency time less than 300  $\mu$ s has been conceived and implemented.

An architecture of seven VMEbus stations equipped with single board computers, all connected through one real-time network has been conceived. The seven stations have been dedicated:

- Three stations (processors) dedicated to the real time data acquisition
- Four stations (controllers) drive the control power amplifiers

The flexibility of hardware allows the implementation of a large number of different strategies of control, among them the most interesting are:

- MHD mode control
  - stabilisation of Resistive Wall Modes
  - interaction with internally resonant modes, to either mitigate or excite their amplitudes or their phases
- “Virtual ideal shell” close to the plasma

Project 2:

#### ***Diagnostic developments***

The work included the improvement of existing RFX diagnostic systems, the study, design and operation of totally new diagnostic systems for RFX-mod, the development and use of diagnostics in other fusion experiments. The group also participated in the study and preliminary design of diagnostics systems for ITER. The main diagnostic systems developed

under the supervision or with the collaboration of DIE members are:

Thomson Scattering Diagnostics: For operations in RFX-mod a completely new system has been designed and built with the objective of increasing the spatial and time resolution of the electron temperature and density measurements. The new system is based on a new Nd:YLF, multipulse laser system and can measure 84-point profiles with 6 mm spatial resolution at a repetition rate of 50 Hz. To work with the new laser source a set of 30, fiber optic coupled, new filter monochromators, with avalanche photodiodes as detectors has been developed. Data acquisition electronics has also been replaced by a set of fast ADCs, markedly increasing the information collected from each plasma shot. The ruby laser of the old RFX Thomson scattering system has been used as the light source in a completely new, edge Thomson scattering diagnostics, whose objective is the measurement of spatial profiles of electronic temperature and density in 12 scattering positions covering the outer 10 cm of the plasma. The detection system includes a grating spectrometer with an image intensifier CCD camera.

Electrical Diagnostics: A new insertable complex probe array, which combines electrostatic and magnetic measurements, has been designed and built to measure radial profiles of electron density, temperature and plasma floating potential with high radial and temporal resolution in two different toroidal positions. A new system of internal probes (ISIS: Integrated System of Internal Probes) has been realized, with the aim of measuring the floating potential, electron temperature and density, magnetic fields and power fluxes. ISIS includes 244 sensors whose positions are chosen in such a way to be complementary to the measurements obtained from other diagnostic systems, like interferometry, spectrometry, tomography, reflectometry, probes mounted on the manipulator systems and pick-up coils.

Spectroscopic Diagnostics: A Modulated Optical Solid state Spectrometer (MOSS) based on the analysis of the degree of coherence and phase of the incoming light to yield respectively temperature and flow speed of the emitting atoms, has been developed and installed in RFX-mod. In addition, a new spectrometer devoted to the analysis of charge exchange radiation in the spectral region between 450 and 540 nm has been designed and assembled.

Far Infrared (FIR) polarimeter: This system has been modified in order to reduce the noise due to mechanical oscillations caused by magnetic field transients. Modifications include a more rigid frame and a new set of optical mirror mounts made of insulating material. The power of the FIR laser source has also been doubled by replacing the CO<sub>2</sub> pump laser system.

Studies for ITER diagnostics: The research group has actively contributed to the EU activity for the preliminary design of the ITER poloidal polarimeter. In addition, experiments for testing a new polarization modulation technique useful for ITER have been carried out in collaboration with University College Cork, Ireland. Finally an experimental test of the polarization effects on metallic mirrors exposed to a Tokamak plasma has been carried out in Padova, to identify possible sources of errors due to plasma deposition on the mirror surface.

INFN activity: Members of DIE have been associated with INFN (Istituto Nazionale di Fisica della Materia) until its reorganization of 2004-2005. In the framework of the PAIS Projects, INFN has supported a research project on "Development of avalanche photodiode arrays systems for plasma diagnostics", carried out at DIE with the collaboration of Consorzio RFX and the Department of Information Engineering to develop a new detection system based on multielement avalanche photodiodes, suitable for application in Thomson scattering. Some innovative features of this device have been patented by INFN and Consorzio RFX.

### Project 3

#### ***RFX-mod Physics***

The physics activity on RFX-mod can be divided into two main steps.

The first step, based on the results obtained in the original RFX during the previous seven years of operation (1992-1999) [Annex 2], has concerned the conception and preparation of an experimental program optimized to reaching the main aims of the experiment [Annex 3], in the shortest time and in the more reliable way.

The second step, started at the end of 2004 and still under way, has concerned the execution of this program.

In the following we describe the main results obtained so far in this second step.

Initial accomplishments were a rapid reproduction of the passive shell plasma performance of the former RFX where a mode spectrum fairly similar to the previous one could be found while the impurity content of the plasma was lower ( $Z_{\text{eff}} \sim 2$  at  $3 \times 10^{19} \text{ m}^{-3}$ ) which is attributed to the improved shape of the graphite first wall.

The new feedback equilibrium control demonstrated its expected capabilities: plasma position accuracy was achieved within a few mm.

Overall, the development of a variety of operation scenarios was achieved in the first half of 2005.

In July 2005 the new system of 192 saddle coils and amplifiers was commissioned and in August the plasma experiments have been started. A high experimental capability has been demonstrated for the study of resistive wall mode control, for tearing mode studies and virtual shell operation. Here, the essentially complete suppression of all radial field components of the relevant MHD mode spectrum at the plasma edge could be demonstrated. In this situation, a careful optimization of the start up and of the plasma operational scenario resulted in pulse durations of up to 6 shell times, presently limited by the capability of the power supplies [see Annex 4 for more details].

Another achievement is the major improvement of shot-to-shot reproducibility of plasma scenarios enabled by the active control. Furthermore, in controlled discharges the confinement time is up to twice the one measured with comparable parameters on the original RFX device.

The new shell of moderate thickness has proved to fulfill expectations.

Together with the highly flexible active control systems, RFX is now in a position to undertake MHD mode studies of unprecedented quality. Individual experimental situations can be prepared which allow more precise modelling and to address which physical features are of relevance, also with regard to dynamo effects and turbulence features.

In conclusion RFX-mod operations can be expected to lead to new insight in various aspects of MHD physics which are of relevance not only to the RFP, but also to other fusion devices. First improvements of the performance of RFX have been obtained and results promise to lead to further enhancements at higher current levels, beyond the extrapolations which were available from the original RFX device.

Moreover, these activities promise to lead to a further strengthening of the links between the RFP and Tokamak/Stellarator communities, in particular since the modified RFX device is proving to be a facility of high relevance beyond the generic RFP development line.

### Project 4

#### ***ITER***

The design of the International Thermonuclear Experimental Reactor ITER continued during the years 2001-2005, in parallel to the negotiations among the partners to decide the site. On June 2005 it was decided to build ITER in Cadarache (France); the partners will be EU, USA, Japan, Russia, Korea, China and India.

Consorzio RFX gave a significant contribution to the design and development over several areas:

- High power switches for superconducting magnets;
- EMC of components and devices;
- Impact on the electrical network;
- Plasma diagnostics (Thomson Scattering, polarimetry, magnetic transducers)

- Analysis of plasma instabilities and consequent mechanical loads.

Since 2003, Consorzio RFX has been appointed as the leader of the European activities (involving also CEA Cadarache, IPP Garching, KFK Karlsruhe and UKAEA Culham) for the development of the Neutral Beam Injectors of ITER. Each of them is basically composed by a negative ion ( $D^+$ ) source, an electrostatic accelerator capable of a 1 MV voltage, 40A current and a neutralizer; a net power of 16.5 MW should be injected into the plasma under continuous operation.

RFX has been responsible of:

- the design revision of the whole injector;
- the design studies for the integration of a single-gap accelerator and a radiofrequency ion source;
- the electrostatic analysis of the 1 MV bushing;
- the design of the SF<sub>6</sub> – insulated transmission line;
- the development of the power supplies, including 1 MV transformers
- the development of the operational plan.

In addition, Consorzio RFX developed the design of a Neutral Beam Test Facility suitable to test all components and the full Injector before installation on ITER. This included also buildings, auxiliary plants, diagnostics, cooling and general services. Consorzio RFX offered to host the Test Facility in Padova.

More details are given in Annex 5.

Project 5:

### ***JET***

JET is the largest thermonuclear fusion experiment presently operating in the world and is presently operated under an European Fusion Development Agreement, involving all the fusion laboratories in the EU.

The main contributions of Consorzio RFX in the development and exploitation of JET in the last five years are summarized in the following areas: participation in the experimental campaigns, disruption prediction and classification, design and construction of new diagnostics.

#### Experimental campaigns

The main results of the scientific work originated from the participation of RFX scientists to many experimental campaigns.

Among the most significant subjects of the scientific work it is worth mentioning particle transport and impurity studies.

Various aspects of particle transport have been analyzed: in particular ITER relevant scenarios like high confinement, low-collisionality plasmas and plasmas with internal transport barriers fuelled by means of pellet injection.

Moreover, again in the ITER perspective, the behavior of heavy impurity density profiles has been carefully studied in discharges characterized by different heating schemes.

#### Disruption prediction and classification

In collaboration with the Department of Electrical and Electronic Engineering of the University of Cagliari, work has been carried out for implementation and test of Neural Network prediction and classification tools of the disruption events in JET. The Disruption is a catastrophic event occurring in the plasma. It is characterized by a sudden loss of the whole plasma thermal energy in a timescale of 1ms and a subsequent decrease of the plasma current in a timescale of 10 ms. This event is the cause of thermal and electromechanical stresses in all the structures surrounding the plasma itself.

#### Halo current sensors

This diagnostic is aimed to evaluate the so called Halo Currents flowing from the plasma to the surrounding conductive structures during a disruptive event. The system should supply a better knowledge of the Halo Currents in terms of current density distribution, localization and rotation as well as toroidal and poloidal current asymmetries.

The HCS system includes 4 identical mechanical structures each including: up to 8 Rogowski coils and up to 2 toroidal pick up coils. The Rogowski coils will directly measure the current flowing through some of the tiles of the upper dump plate. The probes are manufactured to work in an ultra high vacuum environment and to withstand repeated thermal cycles up to 350°C. Presently the commissioning phase of the data acquisition is in progress.

#### Magnetic measurements

This is an important enhancement of the magnetic probe system installed inside the vessel of JET to improve the accuracy of the pick up magnetic measurement, allowing a finer reconstruction of the magnetic surfaces at the plasma edge.

The technology is similar to that adopted for the previous system.

In this system also a set of probes has been integrated and installed close to the ferromagnetic limbs of the mechanical structure of JET to allow measuring the asymmetries introduced by the presence of ferromagnetic masses, to study the saturation effects and the residual magnetic field induction.

#### High Resolution Thomson Scattering

This diagnostic is a new Thomson scattering system for determining the gradients of temperature and density at the edge and at the internal transport barrier with higher spatial resolution and higher repetition rate than the LIDAR system, which is limited respectively to 12 cm and 4 Hz. The design is based on a Nd:YAG laser and filter polychromators, giving 63 position profiles with spatial resolution of 1.5 cm and repetition rate of 20 Hz. The signals are recorded by transient digitizers as in RFX.

#### Project 6

##### ***MPD Thrusters for space applications***

This is an example of the spin-offs from fusion research in Padova

Magneto-Plasma-Dynamic (MPD) thrusters are space propulsion devices, which operate as electromagnetic plasma accelerators and constitute a high power (up to 1 MW) electric propulsion candidate for missions, ranging from orbit raising to interplanetary manned and/or cargo missions of large spacecraft. The acceleration is induced by the interaction between a current, driven by a potential difference between an anode and a cathode, and a magnetic field, which can be a combination of a self-induced (i.e. produced by the plasma current itself) and an externally applied one.

When driven to operate at plasma currents above a threshold value, MPD thrusters have shown a degradation of their performance, in terms of thrust efficiency, accompanied by increased electrodes erosion.

In this respect, a large experimental campaign has been brought out by Consorzio RFX, in collaboration with Centrosazio in Pisa, in order to investigate the role played by plasma phenomena. In particular, a characterization of electron density and temperature, plasma potential and magnetic field fluctuations has been brought out by means of systems of high frequency probes immersed in the plasma. The fluctuation analysis highlighted the relationship between the degradation of the thrust efficiency and the development of magneto-hydrodynamic instabilities, well known in the fusion community as helical kink modes, due to a violation of a stability criterion.

On the basis of the experimental results a successful technique to suppress plasma instability and to reduce the associated detrimental effects on thruster performance has been proposed. By means of this technique, the plasma is driven from a largely fluctuating to a quiescent state, characterized by a dramatic reduction of electrostatic and magnetic fluctuation levels.

As a consequence the power required to sustain the plasma current is observed to largely decrease, with a significant improvement of the thrust efficiency.

These results demonstrate that it is possible to safely drive MPD thrusters to operate at high current regimes and open up new perspectives for their development and future use in long-distance space missions.

4.b	Risorse personale Human resources		
	<p><b>Professors</b>            BAGATIN Mario            BUFFA Antonio            DESIDERI Daniele            FIORENTIN Pietro            GIUDICOTTI Leonardo            GNESOTTO Francesco            MALESANI Gaetano            MORESCO Maurizio            ROSTAGNI Giorgio            SONATO Piergiorgio            ZILLI Enrico            ZOLLINO Giuseppe</p> <p><b>Administrative staff</b>            CECCONATO Serena            FERRARI Enzo            PATANE' Massimiliano            SORGATO Oscar            SOTTOCORNOLA Cristina            ZAVA Paolo</p> <p><b>Technical Staff</b>            BALDO Fabio            CAPOBIANCO Roberto            FASOLO Daniele            LOTTO Luca            MARCOLIN Enrico            MIGLIORATO Luisa            SCEK OSMAN Enrico            TISO Andrea            TOLLIN Marco            VINANTE Carlo            ZAMENGO Tarcisio            ZELLA Daniele</p> <p><b>PhD Students</b>            Boboc Alexandru            Fattorini Luca            Zaniol Barbara            Barana Oliviero            Vianello Nicola            Bettella Denis            Cenedese Angelo            Predebon Italo            Regnoli Giorgio            Piovesan Paolo            Zuin Matteo            Cavinato Mario            Lorenzini Rita            De Pasqual Lucia</p>	<p>Full Professor            Full Professor            Associate Professor            Associate Professor            Assistant Professor            Full Professor            Full Professor            Associate Professor            Full Professor            Associate Professor            Associate Professor            Associate Professor</p> <p>(with Centro Ricerche            Fusione, see sect. 3)</p> <p>(with Centro Ricerche            Fusione, see sect. 3)</p> <p>Energetica XIV ciclo            Energetica XIV ciclo            Energetica XIV ciclo            Energetica XV ciclo            Energetica XV ciclo            Energetica XVI ciclo            Energetica XVI ciclo            Energetica XVI ciclo            Energetica XVI ciclo            Energetica XVI ciclo            Energetica XVII ciclo            Energetica XVII ciclo            Energetica XVII ciclo            Energetica XVII ciclo            Energetica XVII ciclo            Energetica XVIII ciclo</p>	<p>Until April 2005</p> <p>From October 2002 to October 2003</p> <p>Until October 2001</p> <p>From November 2002            Until December 2001            From February 2005</p> <p>From September 2003</p> <p>Until September 2004            From September 2002 to April 2003            From September 2002</p> <p>Until 2001            Until 2001            Until 2001            Until 2002            Until 2002            From 2001 to 2003            From 2001 to 2003            From 2001 to 2003            From 2001 to 2003            From 2002 to 2004            From 2002 to 2004            From 2002 to 2005            From 2002 to 2005            From 2003 to 2005</p>

	<p>Gazza Erica Energetica XIX ciclo From 2004 to 2006</p> <p>Dalla Palma Mauro Energetica XIX ciclo From 2004 to 2006</p> <p>Agostinetti Piero Energetica XX ciclo From 2005 to 2007</p> <p>Auriemma Fulvio Energetica XX ciclo From 2005 to 2007</p> <p>Zabeo Luca Elettrotecnica XIV ciclo Until 2001</p> <p>Grando Luca Elettrotecnica XV ciclo Until 2002</p> <p>Zanotto Loris Elettrotecnica XV ciclo Until 2002</p> <p>Basso Francesco Elettrotecnica XVIII ciclo From 2003 to 2005</p> <p>Sias Giuliana Elettrotecnica XIX ciclo Form 2004 to 2006</p> <p>Soppelsa Anton Elettrotecnica XX ciclo From 2005 to 2007</p> <p>Taccon Cristiano Elettrotecnica XX ciclo From 2005 to 2007</p>
5.b	<p>Risorse finanziarie [media quinquennale]</p> <p>Financial resources</p>
	<p><i>[ la somma di finanziamento ordinario d'Ateneo finanziamenti specifici d'ateneo, finanziamenti specifici da enti di ricerca locali, nazionali e internazionali, finanziamenti da contratti con enti privati.]</i></p> <p><i>1. Annual contributions to Consorzio RFX</i></p> <p><i>2001: ENEA 5.000 mil. Lit.</i>  <i>CNR 4.438 mil. Lit..</i>  <i>Euratom 13.875 mil. Lit.</i>  <i>Others 1.298 mil. Lit.</i></p> <p><i>2002: ENEA 5.169 KEuro</i>  <i>CNR 2.292 KEuro</i>  <i>Euratom 5.427 KEuro</i>  <i>Fondazione CaRiPaRo 800 KEuro</i>  <i>Supply contract 510 KEuro</i></p> <p><i>2003: CNR 1.259 KEuro</i>  <i>Euratom 2.074 KEuro</i></p> <p><i>2004: ENEA 2.500 KEuro</i>  <i>CNR 1.259 KEuro</i>  <i>Euratom 4.728 KEuro</i></p> <p><i>2005: ENEA 2.500 KEuro</i>  <i>CNR 1.259 KEuro</i>  <i>Euratom 3.459 KEuro</i></p> <p><i>In the years 2001 through 2003, a total amount of 7.406 KEuro has been spent for investments for the machine modifications described in Sect.3b.4, Project 1.After subtracting from the above contributions this amount and the general expenses, the budget available for research (including minor investments) has been in the period:</i></p> <p><i>2001: 5.400 mil. Lit</i>  <i>2002: 2.600 KEuro</i>  <i>2003: 2.500 KEuro</i>  <i>2004: 2.500 KEuro</i>  <i>2005: 2.700 KEuro</i></p> <p><i>Note : for an evaluation of the role of DIE personnel in managing and utilizing this budget, see Sect.3b.3 (Introduction to this Program).</i></p>
6	<p>Attrezzature scientifiche, laboratori, officine</p> <p>Scientific equipment, laboratories, workshops</p>
	<p>- RFX-mod: a toroidal device for magnetically confined plasmas in Reversed Field pinch</p>

	<p>configuration: major radius 2.0 m, minor radius 0.5 m, max plasma current 2.0 MA</p> <ul style="list-style-type: none"> <li>- Two step-down transformers 380 kV/20 kV, nominal power 50 MVA each</li> <li>- Modular system of thyristor converters, total installed power 400 MVA</li> <li>- IGCT and IGBT converters for special purpose</li> <li>- Centralized control and data acquisition system</li> <li>- Diagnostic equipment for high temperature plasmas</li> <li>- Ultra-high vacuum laboratory</li> <li>- Electro-optic instrumentation laboratory</li> <li>- Electronic workshop</li> <li>- Electric workshop</li> <li>- Mechanical workshop</li> </ul>
7	Rapporti con altri istituti di ricerca a livello locale, nazionale e internazionale Collaborations with research institutions
7.a	<p><i>[specificare concretamente quanto indicato sotto collaborazioni istituzionalizzate indicate al punto 1 della scheda di Dipartimento]</i></p> <ol style="list-style-type: none"> <li>1. Collaborations with other RFP laboratories: <ul style="list-style-type: none"> <li>• Royal Institute of Technology (Alfvén laboratory) Stockholm (Sweden), T2R Experiment: Electrostatic and magnetic turbulence in the edge region and Alfvén waves, MHD and particle transport experimental studies, Feedback of resistive wall modes</li> <li>• AIST, Tsukuba (Japan), TPE-RX Experiment: Density measurements and pellet injection, Transport analysis, Realization, test and utilization of a new concept Gas Puffing Imaging diagnostic</li> <li>• University of Wisconsin, Madison (USA), MST Experiment: Magnetic and tomographic reconstructions, Dynamo electric field measurements, Heat pulse propagation studies, Impurity studies, Development and use of a “multicolor” SXR tomography</li> </ul> </li> <li>2. Collaborations with Tokamak laboratories: <ul style="list-style-type: none"> <li>• Culham laboratory, UKAEA (U.K.), JET Experiment: see Sect. 3b.4, project 5.</li> <li>• -ENEA-FUS, Frascati (Italy), FTU Experiment: Impurity transport studies, Deep fuelling experiments with high field side pellet injection, Experimental evaluation of the transport of metallic impurities in “full current drive” plasmas</li> <li>• Max Planck-Institut für Plasmaphysik (IPP), Garching (Germany), ASDEX Upgrade Experiment: particle transport analysis and impurity transport studies, magnetic analysis and MHD studies, vertical displacement events and related halo current investigations, Plasma disruption prediction</li> <li>• CEA, Cadarache (France), Tore Supra Experiment: Physics of pellet ablation and deposition, Real-time determination of suprathreshold electron emissivity profile, Thermal analysis of a Lower Hybrid Antenna for plasma heating and current drive. Other Experiments: Characterization and spectroscopic investigation of the Kamaboko Negative Ion Beam Source for ITER</li> </ul> </li> <li>3. Collaborations with Italian Universities inside PRIN (Progetti di Ricerca di Interesse Nazionale): <ul style="list-style-type: none"> <li>• Università di Cosenza: Statistical properties of turbulence.</li> <li>• Università di Milano Centrale: Formation of coherent structures in plasmas.</li> <li>• Università di Pisa: Nonlinear phenomena and transport, Magneto plasma dynamic thrusters.</li> <li>• Politecnico di Torino: Magneto hydro dynamic analysis.</li> <li>• Università di Bologna and Università di Napoli: Magneto plasma dynamic propulsion studies.</li> </ul> </li> </ol>
7.b	<p><i>[Indicare collaborazioni personali non istituzionalizzate ma rilevanti per il programma]</i></p> <ul style="list-style-type: none"> <li>• Institute of Plasma Physics-Academy of Sciences, Prague (Czech Republic): Coherent</li> </ul>

	<p>structures studies, Fluctuations measurements with innovative probes, Electrostatic turbulence control experiments</p> <ul style="list-style-type: none"> <li>• CRPP, Ecole Polytechnique Federale de Lausanne, (Switzerland): Thomson Scattering measurements on the TCV experiment</li> <li>• University College, Cork (Ireland): Polarimetry</li> <li>• Centro Spazio, Pisa (Italy): Electrostatic turbulence and kink instabilities on Magneto-Plasma Dynamic Thrusters in Magnets Plasma Dynamic Thrusters (granted by the European Space Agency [ESA]), Radiation imaging photocamera (in collaboration with INFN)</li> <li>• Università di Udine (Italy): Magnetic analysis</li> <li>• Università di Cagliari (Italy): Neural network applications</li> <li>• Consorzio CREATE, Napoli (Italy): Magnetic analysis.</li> </ul>
8	<p>Collaborazioni con l'industria Collaborations with industry</p>
	<p>Fusion research requires the development of a wide range of innovative technologies and for this reason RFX is working in strict collaboration with primary European companies. In the reporting period, the most important industrial contracts were signed with:</p> <ul style="list-style-type: none"> <li>- ASI Robicon (Milano)</li> <li>- EEI (Vicenza)</li> <li>- Babcock Noell (Germania)</li> <li>- Tesla (Gran Bretagna)</li> <li>- Siemens (Germania)</li> </ul> <p>Several spin-offs have been generated from fusion research carried out at Consorzio RFX in the years 2001-2005. Among the most interesting:</p> <ul style="list-style-type: none"> <li>- design and construction of a reactive power compensator for railway appliances;</li> <li>- development of magnetron sputtering techniques; in particular, the application to the textile industry has been the subject of a patent;</li> <li>- development of magneto-plasma dynamic thrusters for space applications (see Sect.3b.4, project 6): in particular, an innovative device for controlling the magnetohydrodynamic instabilities has been the subject of a patent.</li> </ul>
9	<p>Altre attività rilevanti per la ricerca, a livello di Programma Other research-related activities</p>
	<p><i>[organizzazione di seminari e convegni, partecipazione a seminari e convegni, ecc..]</i></p> <p>Consorzio RFX organized the 23rd Symposium on Fusion Technology (SOFT), Venice, 20-24 September 2004. The Chairman was prof. Francesco Gnesotto. SOFT is the most important biennial conference on fusion technology and engineering; in Venice it has been attended by over 570 participants from 25 different countries.</p> <p>Consorzio RFX also organized in Padova:</p> <ul style="list-style-type: none"> <li>- the 10<sup>th</sup> RFP Workshop, May 2004, under the auspices of the Implementing Agreement of the International Energy Agency</li> <li>- the 4<sup>th</sup> IAEA Technical Meeting on "Negative Ion Based Neutral Beam Injectors", May 2005, co-organized with the International Atomic Energy Agency</li> <li>- the 13<sup>th</sup> European Fusion Physics Workshop, 14-16 December 2005, sponsored by the European Commission.</li> </ul>
11	<p>Prodotti della ricerca Research outcome</p>
11.b	<p><i>[per ogni anno del quinquennio la quantità totale dei prodotti del programma secondo la tipologia CINECA, indicare anche eventuali prodotti che non rientrano in questa tipologia.]</i></p>

<i>Research products</i>					
	<i>2001</i>	<i>2002</i>	<i>2003</i>	<i>2004</i>	<i>2005</i>
Refereed Journal Papers	29	44	47	37	67
Proceeding Papers	40	21	41	35	39
Patents			1	1	1

The following table gives the number of products whose authors are with DIE.

<i>Research products</i>					
	<i>2001</i>	<i>2002</i>	<i>2003</i>	<i>2004</i>	<i>2005</i>
Refereed Journal Papers	10	6	11	5	14
Proceeding Papers	4	2	4	7	5
Patents			1		1

11.c

[*indicare i prodotti più rappresentativi con un massimo di 5 per l'intero quinquennio*]

*A- Journal papers*

1. P. Martin, S. Martini, V. Antoni, L. Apolloni, M. Bagatin, W. Baker, O. Barana, R. Bartiromo, P. Bettini, A. Boboc, T. Bolzonella, A. Buffa, A. Canton, S. Cappello, L. Carraro, R. Cavazzana, G. Chitarin, S. Costa, F. D'Angelo, S. Dal Bello, A. De Lorenzi, D. Desideri, D. Escande, L. Fattorini, P. Fiorentin, P. Franz, E. Gaio, L. Garzotti, L. Giudicotti, F. Gnesotto, L. Grando, S.C. Guo, P. Innocente, A. Intravaia, R. Lorenzini, A. Luchetta, G. Malesani, G. Manduchi, G. Marchiori, L. Marrelli, E. Martines, A. Maschio, A. Masiello, F. Milani, M. Moresco, A. Murari, P. Nielsen, M. O'Gorman, S. Ortolani, R. Paccagnella, R. Pasqualotto, B. Pegourie, S. Peruzzo, R. Piovan, N. Pomaro, A. Ponso, G. Preti, M.E. Puiatti, G. Rostagni, F. Sattin, P. Scarin, G. Serianni, P. Sonato, E. Spada, G. Spizzo, M. Spolaore, C. Taliercio, G. Telesca, D. Terranova, V. Toigo, L. Tramontin, M. Valisa, N. Vianello, M. Viterbo, L. Zabeo, P. Zaccaria, P. Zanca, B. Zaniol, L. Zanotto, E. Zilli, G. Zollino: "New insights into MHD dynamics of magnetically confined plasmas from experiments in RFX", *Nuclear Fusion*, **42** (2002) 247-257
2. P. Sonato, G. Chitarin, P. Zaccaria, F. Gnesotto, S. Ortolani, A. Buffa, M. Bagatin, W.R. Baker, S. Dal Bello, P. Fiorentin, L. Grando, G. Marchiori, D. Marcuzzi, A. Masiello, S. Peruzzo, N. Pomaro, G. Serianni, "Machine modification for active MHD control in RFX", *Fusion Engineering and Design* **66-68** (2003) 161-168
3. M. Bagatin, G. Chitarin, D. Desideri, A. Murari, R. Piovan, L. Zabeo: "Integration of magnetic and non-magnetic measurements for current profile reconstruction in RFX", *Review of Scientific Instruments* **72**, 1, (2001) 426-429

*B- Instruments and devices*

4. Design, construction, installation and operation of the RFX-mod load assembly. It includes the graphite first wall, the copper shell, the toroidal structure and the 192 control coils (see Sect. 3b.4, project 1). The system has been designed in 2001, built in 2002-2004, installed in 2004 and tested in 2004-2005. It allowed to significantly improve the performance of RFX (see Sect. 3b.4, project 3).
5. Design, construction and installation of the Halo Current Sensors on the JET machine (see Sect. 3b.4, project 5). JET is the largest fusion device in the world. The HCS system is a new diagnostic instrument, whose main aim is to determine

	amplitude, spatial distribution and time behavior of the currents flowing from the plasma to the wall. These currents, interacting with the intense magnetic field, produce forces that are one of the main issues in ITER design.

P.S. Nel caso in cui le informazioni disponibili non siano compatibili con il presente modulo è possibile allegare documentazione cartacea indicando negli appositi campi i numeri dei relativi allegati.