Divertor Test Tokamak: An Italian proposal to pave the path to Nuclear Fusion resource

Nuclear Fusion, once realized, would have the advantages to ensure sustainability and security of supply, no production of greenhouse gases, intrinsic safety; environmentally responsible. Italy plays an acknowledged role in international nuclear fusion research, strengthened in the years thanks to educational and training actions of universities and research institutions as well as to a fruitful involvement of the national industries. The proposal for the realization of a Divertor Tokamak Test Facility in Italy has been brought forward backed by the Italian Fusion scientific and technological community in the field of EU Fusion Program

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Energy demand is expected to more than double by 2050 as the combined effect of the increases of population and energy consumption per capita in developing countries. Energy sources that can prove their long-term sustainability and security of supply must replace fossil fuels. The solution to the energy problem can only come by a portfolio of options that includes improvements in energy efficiency and renewable energy, nuclear fission and carbon capture and sequestration. The alternative of Nuclear Fusion, once realized, would have the advantages to ensure sustainability and security of supply (fuels are widely available and virtually unlimited), no production of greenhouse gases, intrinsic safety (as no chain-reaction is possible); environmentally responsible: no generation of radioactive waste and – with a proper choice of materials for the reaction chamber – the produced radioactivity would decay in a few tens of years.
With the strong impulse given by an energy policy driven by the reduction of CO_2 emissions, fusion could realize its first demonstrative plant (DEMO) in the second half of this century and give a strong contribution for the base power load towards the beginning of the new century.
Nuclear fusion is the process that powers the sun and the stars, making life on Earth possible. It is named "fusion" because the energy is produced by combining light nuclei, such as hydrogen isotopes, at extremely high temperatures. In this process part of the mass of the reactants is converted into kinetic energy of the reaction products (helium and a neutron for the hydrogen isotopes deuterium-tritium reaction), which in turn can be used to produce electric energy in a standard steam turbine cycle.

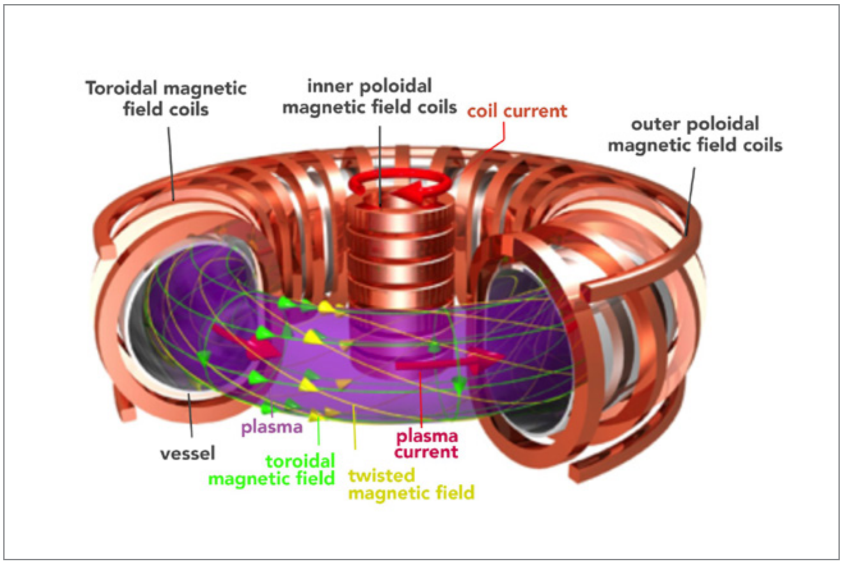
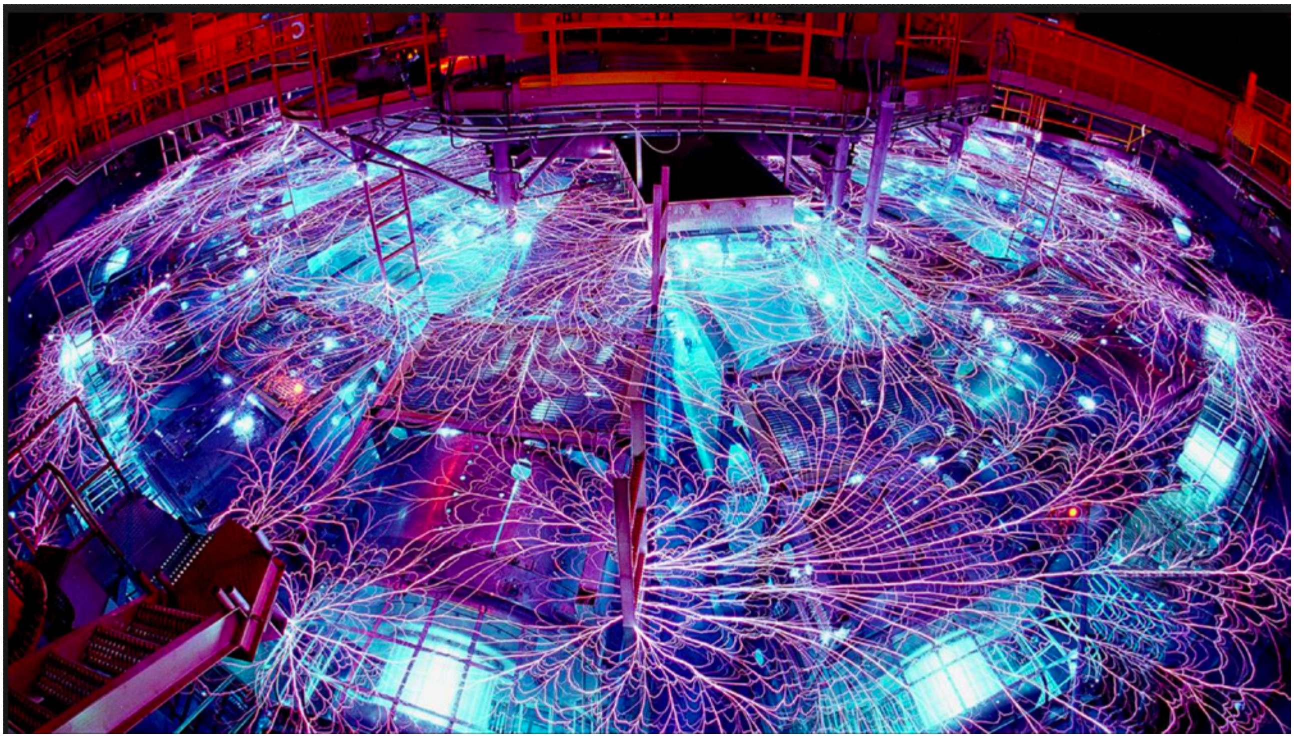


Fig. 1 Schematic view of magnetic confinement in a Tokamak

At the extremely high temperature needed to achieve fusion on Earth, the fuel is in the plasma state, a particular gas where its components are ionized, i.e. composed by ions and electrons. In the magnetic confinement approach (alternative to the inertial one where fusion takes place before fuel can expand and touch the walls) the fusion fuel is kept "detached" from the wall of the reactor device, among which the "Tokamak" configuration [1.1] has achieved the best performance (Figure 1).
At the edge of the plasma a thin (few centimeters) region of open field lines is created (the SOL) through which charged particles and heat flowing out of the plasma core are guided into the so-called divertor, where the plasma impinges on material surfaces (the divertor target plates). This divertor region is the place where the largest part of the power contained in the vacuum vessel must be exhausted. Since the heat flux flowing along the magnetic field lines in the SOL region of a reactor is expected to be even higher than that on the sun's surface, the *"power exhaust"* problem is definitely one of the most challenging in view of the fusion power achievement.
The EU Fusion Program coordinates the activity of 29 countries, with a common vision, highlighted in a "Roadmap" [1.2] aiming at the generation of electrical power with a Demonstration Fusion Power Plant (DEMO) by 2050. In its path, EU roadmap foresees two important milestones:

- ITER [1.3], the international tokamak experiment presently under construction in the south of France (Cadarache), see Figure 2, which should solve the remaining open physics issues before moving to the realization of the above mentioned DEMO,
- an R&D activity, articulated in 8 Missions, to tackle the main challenges in achieving Fusion reactor accomplishment goal.

In particular a dedicated Mission (M.2) has been devoted to the pow-



er exhaust issue, identified as a potential show-stopper on the fusion roadmap. Part of the terms of reference for the Divertor Test Tokamak (DTT) Project are articulated within Roadmap Mission 2: “Heat-exhaust systems”.
An important constraint in the design of the DTT facility is the necessity to operate in a plasma physics regime as close as possible to a reactor one; this fact is realizable by operating with edge and bulk parameters [31.4] adequately scaled to reproduce as close as possible ITER/DEMO like conditions.

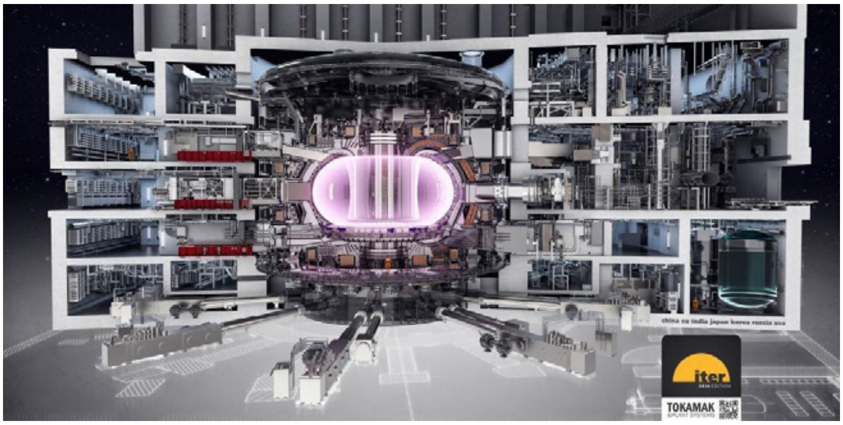


Fig. 2 Artistic view of ITER, under construction at Cadarache in the South of France

Italy plays an acknowledged role in international nuclear fusion research, strengthened in the years thanks to educational and training actions of universities and research institutions as well as to a fruitful involvement of the national industries, paying attention to innovation and giving rise to a virtuous circle that enriches the country. Italian fusion research is carried out under the aegis of MISE (Ministero dello Sviluppo Economico - Ministry of Economic Development) and MIUR (Ministero dell’Istruzione, Università e Ricerca - Ministry of Education, University and Research) in several laboratories: ENEA in Frascati, Consorzio RFX in Padua, Istituto di Fisica del Plasma del CNR in Milan, Consorzio CREATE in Naples – which coordinates the activities of several universities in Southern Italy – INFN with its labs in Legnaro, together with the important contributions of a number of other Italian universities ranging from Politecnico of Torino and Milano to University of Padua down to Catania and Cagliari passing from the three universities of Rome. These groups have been working together for years under the umbrella of EURATOM-ENEA Association in the framework of EFDA (European Fusion Development Agreement), and from 2014 of the EUROfusion Consortium agreement.

There are significant results achieved at the Italian labs. In Frascati, FTU held the world record of the fusion performance parameter (triple product) for years and now is a leader in the study of new first wall materials: Liquid Metals. FTU is indeed operating in presence of liquid Lithium and Tin. In Padua RFX-mod owns the unique capability to explore the Reversed Field Pinch configuration at plasma currents up to 2MA and it is equipped with a sophisticated magnetic feedback system. Italian researchers also gave a significant contribution to the design and operation of JET and are significantly contributing to the design and construction of ITER. Italy is also building in Padua the facility for full-scale testing of ITER Neutral Beam Injectors. Italian researchers, meanwhile, play a key role in the fusion roadmap, leading several Work Packages in the Horizon 2020 Workprogramme. Eventually, along the years a strong cooperation/integration has been realized and consolidated between the research system and the Italian national industry. This cooperation has allowed the national industry to play a major role in the realization of the international experiment ITER [1.3]. *So far, about 1 billion of procurement contracts have been awarded to the Italian industries for a fraction of about 56%, against an Italian contribution to the project lower than 10%.* But the most important point to be underlined is that, in several cases, this participation has allowed our industries to further improve their high level technological skills and develop new ones that have been reused out of fusion to conquer important market sectors, even during the recent, very serious, economic crisis time.

Taking into account the Italian role in nuclear fusion research, the proposal for the realization of a DTT facility in Italy has been brought forward backed by the Italian Fusion scientific and technological community. This community boasts a broad expertise covering all field involved in Fusion, from Plasma Theory to Plasma Engineering, from Nuclear Engineering to Remote Handling, from Superconductor to High Power Heating Systems and Power Supply.

The DTT proposal is among the projects submitted to Juncker's plan (EFSI: European Fund for Strategic Investments) with a budget of 500 million Euro.

The "Construction of a Divertor Tokamak Test Facility for fusion energy research", DTT proposal, is in the list "Knowledge, SMEs and the digital economy" presented by ENEA and Italian Ministry of Economic Development.

In March 2015 the EUROfusion General Assembly welcomed the opportunity of gaining additional resources for the DTT, suggesting that the conceptual activities, the definition of the objectives and the design

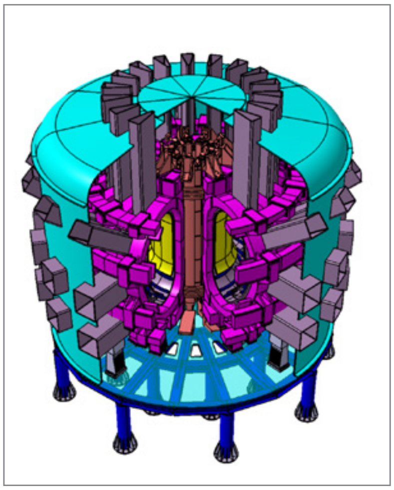


Fig. 3 Sectional view of DTT tokamak basic machine

were carried out in a truly European framework with Work Packages DTT1 and DTT2.

Recently (April 2017) the Industry Commission of the Italian Parliament has approved a motion committing the Government to fund the project.

An internationalization workshop meeting of the proposal is being called by EUROfusion and is in advanced phase of preparation to be held in Frascati June 19-20, 2017.

The present DTT proposal [41.5] has been elaborated by an International European Team of experts. Its contents has been independently revised and recommended by Chinese experts. This joint work demonstrates the possibility to set up a facility able to bridge the power handling gaps between the present day devices, ITER and DEMO. Letters of interest have been sent by the Responsible of Fusion Programme of the China Academy of Science and by the Corean President of the National Fusion Research Institute declaring they willingness to participate to the Italian DTT proposal considering in

kind contributions.
DTT machine has been designed with a major plasma radius of 2.15 m to compromise wit budget constrain, but still guaranteeing the necessary flexibility in the divertor region to allow testing different magnetic topologies and different divertor geometries and/or materials (including liquid metals). The relatively high toroidal field (B_T=6T) will give the possibility to achieve plasma parameters not far from the DEMO ones,. The plasma parameters achievable in such a machine satisfy the expected design goal and have been benchmarked in several ways, by using the knowledge provided by the present ongoing experiments and, of course, verified with the more sophisticated modelling tools available, where all the main physics aspects are included.

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