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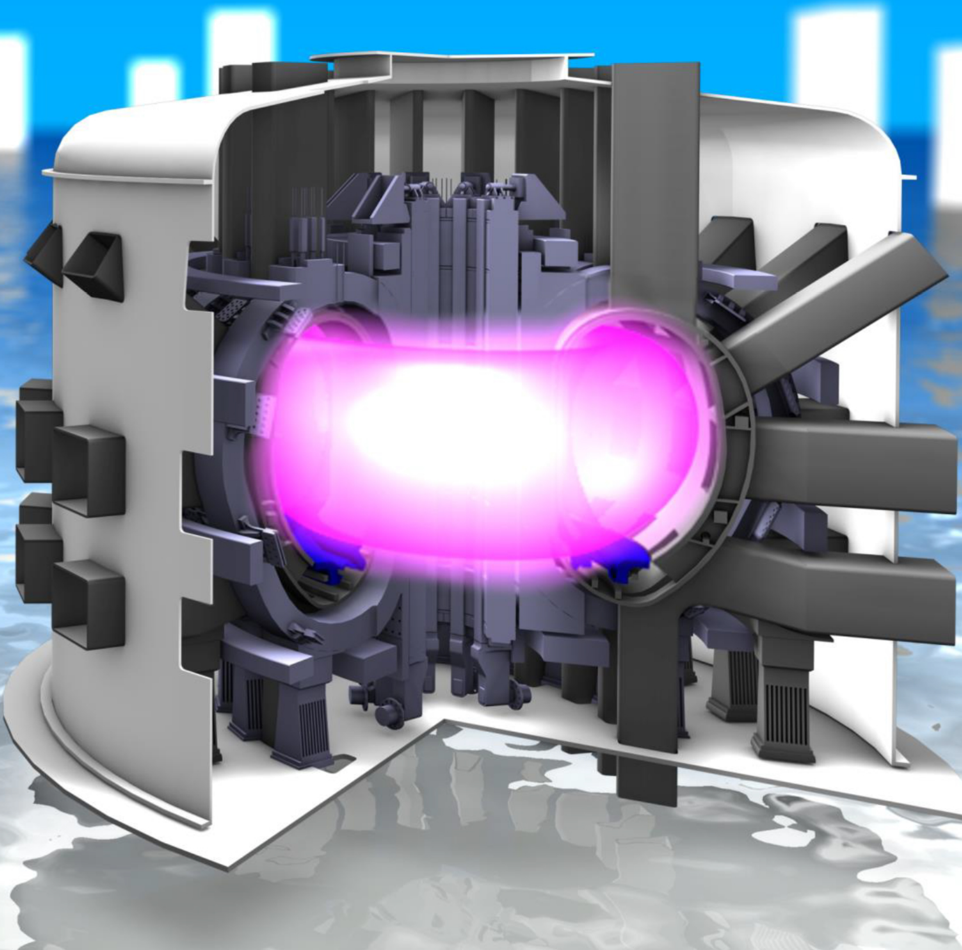
DTT

Divertor Tokamak Test facility Project Proposal

Report short version



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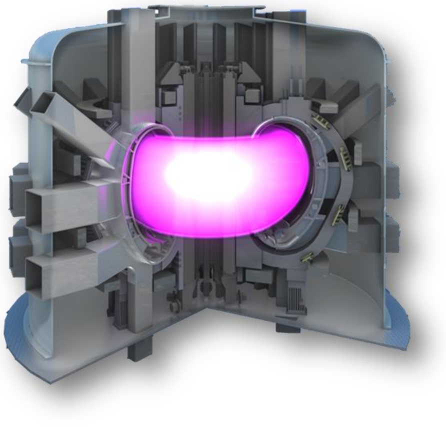
Divertor Tokamak Test facility
Project Proposal

REPORT SHORT VERSION

A milestone along the roadmap
to the realisation of fusion energy



January 2016

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DTT
Divertor Tokamak Test facility – Project Proposal - Report Short version

Italian National Agency for New Technologies,
Energy and Sustainable Economic Development

Edited by Aldo Pizzuto, ENEA

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This note contains a brief overview of the project proposal DTT, Divertor Tokamak Test facility, described in analytical form in the volume "DTT Divertor Tokamak Test facility. Project Proposal" published by ENEA in July 2015, ISBN: 978-88-8286-318-0. For all details, the full publication is available, in electronic format, on the web site
http://fsn-fusphy.frascati.enea.it/DTT_ProjectProposal_July2015.pdf
and in paper form on request.
Aim of this note is to provide the key data of the complex and articulated project which involved about a hundred researchers from Italian and foreign universities and laboratories, coordinated by R. Albanese (Università di Napoli Federico II, Italy and CREATE, Italy), F. Crisanti (ENEA, Italy), R*. Martone (Seconda Università di Napoli, Italy and CREATE, Italy) and A. Pizzuto (ENEA, Italy).*
Thanks to the qualification and dedication of the project team, an innovative and thorough proposal has been developed, aiming to provide a significant step in the road map towards the implementation of energy from controlled thermonuclear fusion.
A possible European funding of the proposal, within the framework of the European Plan for Infrastructure Investments, will allow the start-up of a challenging experimental program that, within a few years, will provide scientific, technical and technological crucial answers in the field of renewable innovative energy sources and, in addition, will provide a strong boost to the most advanced industry's and, therefore, to employment levels.

The coordination team.
R. Albanese, F. Crisanti, R. Martone, A. Pizzuto.

January 2016

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This proposal is synergic with the activities carried out within the EUROfusion work packages:
"WPDTT1 - Assessment of alternative divertor geometries and liquid metals PFCs", Project Leader H. Reimerdes;
"WPDTT2 - Definition and Design of the Divertor Tokamak Test Facility", Project Leader R. Albanese.
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Contributors

ENEA, Italy

L. Affinito
A. Anemona
M. L. Apicella
P. Batistoni
G. Calabrò
A. Cardinali
S. Ceccuzzi
C. Centioli
V. Corato
P. Costa
F. Crisanti
A. Cucchiaro
A. Della Corte
G. De Marzi
A. Di Zenobio
C. Fiamozzi Zignani
L. Gabellieri
A. Lampasi
G. Maddaluno
G. Maffia
D. Marocco
G. Mazzitelli
G. Messina
F. Mirizzi
M. Moneti
L. Muzzi
A. Pizzuto
G. Ramogida
G.L. Ravera
R. Righetti
S. Roccella
F. Starace
G. Tomassetti
A. Tuccillo
O. Tudisco
S. Turtù
S. Villari
B. Viola
V. Vitale
G. Vlad
P. Zito
F. Zonca

ENEA - CNR - IFP, Italy

A. Bruschi
D. Farina
L. Figini
S. Garavaglia
G. Granucci
M. Lontano
D. Micheletti
S. Nowak
C. Sozzi

ENEA - CREATE, Italy

R. Albanese
R. Ambrosino
L. Barbato
S. Ciattaglia
D. Coccorese
V. Coccorese
M. de Magistris
G. Di Gironimo
V. P. Loschiavo
R. Martone
D. Marzullo
S. Mastrostefano
S. Minucci
R. Mozzillo
R. Palmaccio
V. Pericoli-Ridolfini
A. Pironti
G. Rubinacci
A. Tarallo
S. Ventre
F. Villone

ENEA - Politecnico di Torino, Italy

R. Maggiora
D. Milanesio

ENEA - RFX, Italy

P. Agostinetti
T. Bolzonella
L. Carraro
A. Fassina
P. Franz
E. Gaio
F. Gnesotto
P. Innocente
A. Luchetta
G. Manduchi
L. Marrelli
P. Martin
S. Peruzzo
R. Piovan
M. E. Puiatti
G. Spizzo
P. Scarin
P. Sonato
M. Spolaore
V. Toigo
M. Valisa
L. Zanotto

Univ. degli Studi di Milano - Bicocca, Italy

G. Gorini

CEA, IRFM, France

G. Giruzzi

CRPP - EPFL, Switzerland

B. Duval
H. Reimerdes

FOM-DIFFER, The Netherlands

M. de Baar

IPPLM, Poland

R. Zagórski

Synopsis

The recent establishment of the EURO*fusion* Consortium marks a big step in the roadmap toward the realisation of fusion energy with a demonstration plant DEMO by 2050.

One of the main challenges in the roadmap is to develop a heat and power exhaust system able to withstand the large loads expected in the divertor of a fusion power plant. Therefore, in parallel with the programme aimed to optimise the operation with a conventional divertor based on detached conditions to be tested in ITER, EUROfusion has launched a dedicated project to investigate alternative power exhaust solutions for DEMO, and the design of a new machine named "Divertor Tokamak Test facility" (DTT), to be able of possibly integrating all relevant physics and technology issues. The set of possible alternative solutions to be assessed includes advanced magnetic configurations and liquid metal divertors.

DTT should operate integrating various aspects, with significant power loads, flexible divertors, plasma edge and bulk conditions approaching, as much as possible, those planned for DEMO, at least in terms of dimensionless parameters. An optimal balance between such requirements and the need to realize the new experiment accomplishing the DEMO timescale, led to the choice of the following machine parameters: major radius R=2.15 m, aspect ratio A=3.1 (A=R/a, where 'a' is the tokamak minor radius), toroidal field B_T=6 T, plasma current I_p=6 MA, additional power P_{Tot}=45 MW. The machine will have the possibility to test several different magnetic divertor topologies, in reactor relevant regimes. Different plasma facing materials will be tested (tungsten, liquid metals) up to a power flow in the order of 20MW/m^2. The final target of the experiment is the realization of an integrated solution (bulk and edge plasma) for the power exhaust in view of DEMO. The related studies and experiments will allow a valuable development of innovative technologies in several different fields, with relevant spin off for the industries of all European Countries.

According to the European Road Map, the DTT experiment should start its operation in 2022. To be coherent with this plan, the realization of the device will cover a time of around 7 years, starting from the first tender (during 2016) up to full commissioning and the first plasma (during 2022). The operations should then cover a period of more than 20 years, up to the initial phases of the DEMO realization.

The occupational impact is expected to be significant, with at least 150 people involved for the operation (50 % professionals, 50 % support personnel). In addition, a significant amount of on-site workers are expected during the construction, not to mention the indirect and spin-off opportunities.
The expected economic impact on the hosting territory is also significant. Some financial fall-out for both the construction and the operation should be addressed to the territory (buildings, electrical grid, maintenance, etc.). In addition, the continuous presence of an international scientific staff will cause on the host territory a spin-off linked to the guest family life and activities like lodging, transport, restaurants, schools and so on.
While the European Programme allocated about 60 MEUR in Horizon 2020, the expected total cost for realizing this DTT proposal is estimated to be about 500 MEUR.
DTT is a strategic investment in the key areas of research and innovation, with significant implications on the energetic problem, offering a stimulus on higher education and training in the fields of science and engineering. Recently, the Italian Government has offered to the European fusion system the opportunity to get complementary funding for a dedicated exhaust facility located in Italy. The proposal is among the projects submitted to the 315 billion Euro of Juncker's plan (EFSI: European Fund for Strategic Investments).

This report presents the DTT proposal prepared by an International European Team of experts. Its contents has been independently revised and recommended by Chinese experts. It demonstrates the possibility to set up a facility able to bridge the technological gap between the present day devices and ITER/DEMO. The DTT scientific project is well framed within the European fusion development roadmap, which plays a crucial role for the development of one of the most promising technologies for an alternative, safe and sustainable new energy source.

1. Introduction

One of the main challenges, within the European Fusion Roadmap [1], in view of the construction of a demonstration plant (DEMO, a nuclear fusion power plant able to provide power to the electricity grid by 2050), is the thermal power on the divertor (the main component of the system for the disposal of the plasma thermal power in a fusion plant). In ITER [2], [3] (the International Fusion experiment for magnetically confined plasma, presently under construction in Cadarache, France) it is planned to test the actual possibilities of a "standard" divertor working in a plasma fully detached condition, i.e. no contact between plasma and first wall of the vessel. Unfortunately, this solution could be unsuitable to be extrapolated to the operating conditions of DEMO and future reactors; then the problem of thermal loads on the divertor may remain particularly critical in the road to the realization of the reactor.

For this reason, within the European Fusion Roadmap, a specific project has been launched, aimed to define and design a Tokamak named "DTT (Divertor Tokamak Test)". This Tokamak has to carry out a number of scaled experiments by integrating with the specific physical condition expected and technological solutions included in DEMO. DTT should retain the possibility of testing different divertor magnetic configurations, including liquid metal divertor targets, and other possible solutions promising to face with the power exhaust problem.

Hereby, the present DTT design proposal refers to a set of parameters suitably selected to reproduce edge conditions as close as possible to those expected in DEMO (in terms of a set of dimensionless parameters characterizing the physics of Scrape Off Layer, SOL, and of the divertor region), while fully fitting (again, in terms of the dimensionless parameters) with DEMO bulk plasma performance. The main parameters of DTT have been selected to ensure maximum flexibility, even within the hard limits of a given budget and, in addition, of a time schedule consistent with the needs of the European Road Map.

2. Fusion as a "clean" and "infinite" energy source.

Nuclear fusion is the process that powers the sun and the stars, making life on Earth possible. It is called "fusion" since the energy is produced by combining light nuclei (hydrogen isotopes) at extremely high temperatures (15 million degrees ºK in the sun, more than 100 million degrees ºK in laboratory devices). In the fusion process part of the mass of the reactants is converted into kinetic energy of the reaction products (helium and a neutron for the deuterium-tritium reaction), which in turn can be used to produce electric energy within a standard steam turbine cycle.

Looking ahead, the nuclear fusion is included among the energy sources able to guarantee the world energy sustainability without CO_2 production (i.e. without contributing directly to the greenhouse effect). Therefore, the fusion can effectively contribute in the future to meet the quick growth of the global energy demand, in fact expected to more than doubling by 2050, because of the combined effect of the increases of population and energy needs per person in developing countries.

Nuclear fusion, realized in fusion devices in a controlled way, will provide a source of energy:

- Environment-friendly: the products of the most promising fusion reaction (Deuterium-Tritium, D-T) are Just helium and neutrons. No long-term radioactive wastes arises and, with a proper choice of materials for the reaction chamber, the radioactivity induced in structural components decays in a relatively short time, compared to the values in carbon-fired plants.
- Intrinsically safe: no chain-reaction is possible, since a very small amount of fuel is needed in the vacuum vessel; in case of damage, accident, or loss of control, fusion reactions and heat generation will very rapidly and automatically switch off.
- Sustainability: the fuel, deuterium and lithium (tritium is produced from lithium inside the reactor) are widely available in nature and virtually unlimited (deuterium is abundant in sea water and lithium both in rocks and ocean water).
- CO2-free: there is no production of greenhouse gases.

At the extremely high temperature needed to achieve fusion on Earth, the fuel is in the "plasma state", a particular condition where the atoms are fully ionized, i.e. split in ions and electrons. The containment of such a hot fuel cannot be carried out by a conventional vessel. To solve this issue, two options are available.

The first, named "inertial fusion," consist in compressing and heating by means of powerful laser beams the fusion fuel in a very quick process; as a consequence, the nuclei are forced within distances so short that the fusion reactions are suitably triggered.

The second, named "magnetically confined fusion", uses a magnetic field to maintain the hot fuel "detached" from the wall. The plasma ions and electrons are trapped by the magnetic field, which prevents the transversal movements; however, charged particles can move freely along the parallel direction. If designed in such way to form nested magnetic flux surfaces, the magnetic field acts as a special container, preventing the movement of the charged particles from hitting to the surrounding material walls. Among the magnetically confined devices, the ''tokamak'' has achieved the best performance (see Fig. 1.).

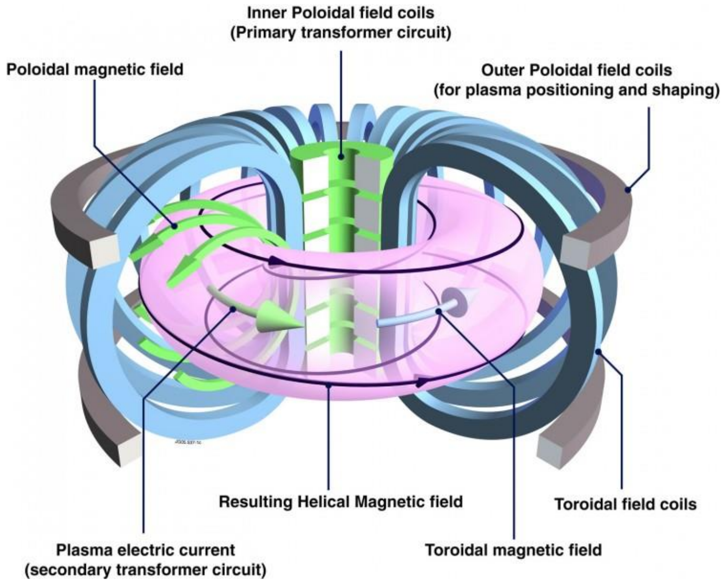


Figure 1. The tokamak: magnetic field coils and the resulting field able to confine the plasma.

3. Power exhaust issues in the fusion roadmap

In 2012 EFDA (European Fusion Development Agreement) published "Fusion Electricity – A roadmap to the realization of fusion energy" **Errore. L'origine riferimento non è stata trovata.**, which sets out a strategic vision toward the generation of electrical power by a Demonstration Fusion Power Plant (DEMO), by 2050.

The roadmap elaborates 8 critical strategic missions to tackle the main challenges in achieving this ambitious goal. In particular, two Work Packages have been launched as part of the mission n. 2 ("*Heat-exhaust system*") of the Road Map with the aim of carrying out alternative solutions to the problem of disposing the heat load:

- "WPDTT1 - Assessment of alternative divertor geometries and liquid metals PFCs (Plasma Facing Components)"
- "WPDTT2 - Definition and Design of the Divertor Tokamak Test (DTT) Facility".

The confinement in a tokamak reactor [3] is the result of magnetic field lines forming a set of closed, nested magnetic surfaces. At the edge of the plasma, a thin (few centimeters) region with open field lines appears (Scrape-Off Layer, SOL) through which, charged particles (and the related energy) flowing out from the core plasma are directed to the divertor plates towards the separatrix (the last closed surface).
The heat flux parallel to the magnetic field, in the SOL region of ITER and DEMO, is expected to be even higher than that on the sun's surface (see Figure 1.).

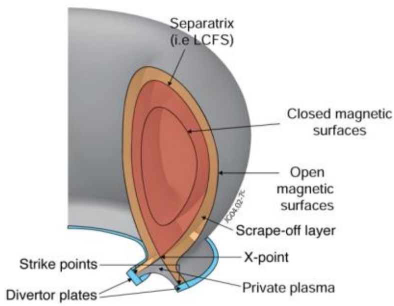
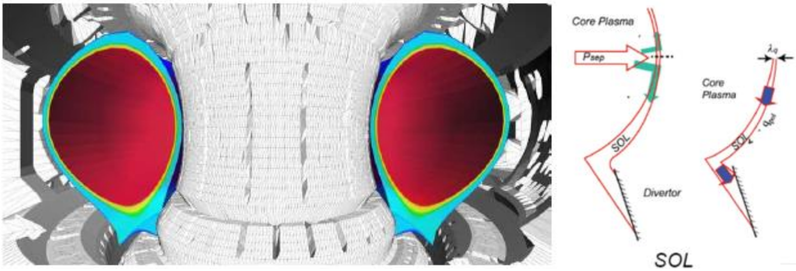


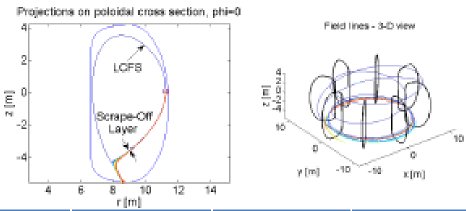
Figure 2: Plasma edge: geometry of the Scrape-Off Layer (SOL) and of the divertor plates.



(courtesy of JET-EUROfusion)

$$q_{pol} \sim \frac{P_{SOL}/2}{2\pi R \lambda_q}$$

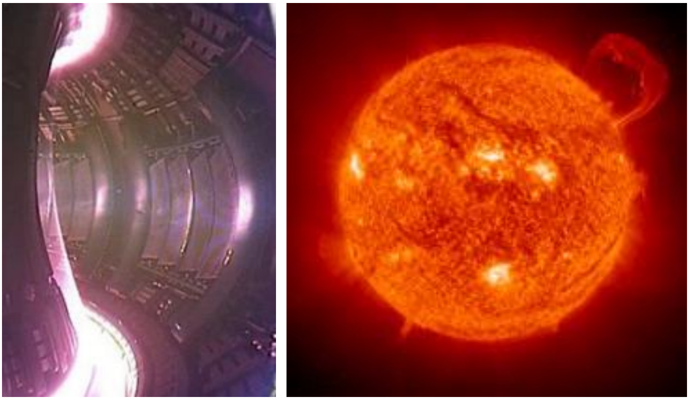
$$q_{\parallel} \sim \frac{P_{SOL}/2}{2\pi R \lambda_q}\frac{B}{B_\theta}$$



Magnetic field lines in ITER

	P_{SOL} (MW)	λ_q (mm)	R (m)	$q_{//}$ (GW/m^2)	q_{pol} (GW/m^2)
JET	~30	~3.5	~3	~0.7	~0.2
ITER	~90	~2	~6	~1.8	~0.6
DEMO*	~150	~1	~9	~5	~2

Figure 3. Divertor heat exhaust challenge in a tokamak: PSOL is the total power flowing in the SOL channel, λq is the decay length of the heat flow at the outboard midplane, R is the major radius, q// is the heat flow parallel to the magnetic field, qpol is the poloidal component of the heath flow.



Extreme conditions:

- *in nucleus: T > 100 M °K*
- *in the SOL: $q_{//} > 1\ GW/m^2$*

The geometry reduces it by a factor of 30:

- *B toroidal >> B poloidal*
- *Expansion of the flux on divertor*
- *Plate inclination*

… … But the heat flow on the plates is still higher than the current technological limits (5-10 MW/m2)

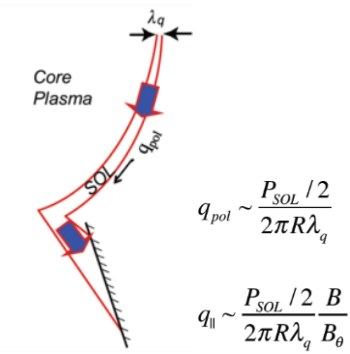


Figure 4. How to cope with large values of the power flux on the divertor: geometry helps, but by itself is not sufficient to handle a heat flux probably higher than that on the sun surface.

The strategy to face with the problem of thermal loads on the divertor in DEMO and, in general, in future reactors, relies upon different factors:

- development of plasma facing components able to cope with very large power fluxes (>5 MW/m2) based on materials of reactor interest;
- selection of the divertor geometry and of the magnetic flux map able to reduce the normal heat flux on the target, and therefore able to distribute the heat over a larger surface;

- removal of plasma energy before it reaches the target via impurity radiation; this goal is pursued by increasing edge plasma density and injecting impurities (other substances than products and reagents) in the SOL region, in such a way the fraction of the heating power that impinges on the divertor s reduced up to a level compatible with the present available technology (15÷20 MW/m2);
- recycling of the particles released by the wall and increase of the density close to the plates, resulting in a "detachment" from the wall of the plasma (the temperature drops below the ionization threshold, the particles become neutral and are not any more constrained by the magnetic field; consequently, no direct energy flow affects the divertor plates).

Any proposed strategy for the solution of thermal loads problem must take into account that:

- present experiments where "detached" plasma conditions are carried out, are characterized by conditions of the SOL region very different from those expected in the ITER and DEMO reactors;
- simulations with the available physics models for the study of SOL are not sufficiently reliable;
- stability of the detachment front has yet to be experimentally assessed for ITER and DEMO conditions;
- various problems might arise related to integration of this solution with the plasma core and the other reactor subsystems, e.g.:
    - impurity contamination of the core with consequent reduction in the efficiency of the confinement and in the general performance of the reactor;
    - compatibility of bulk plasma with the very high requested radiation fraction (> 90%);
    - compatibility with pumping of the particles;
    - monitoring of erosion, temperature, etc.

Moreover, a number of nuclear aspects must be taken into account restricting the use of certain materials (i.e. requirements in terms of life expectancy of reactor components, the need of keeping the temperature low in the divertor region in order to take almost vanishing the erosion rate, etc…).

For these important reasons specific program targeted to the definition and design of the DTT (Divertor Tokamak Test facility) has been launched. This tokamak facility is called upon to undertake scale experiments aimed to look for alternative solutions to the divertor, able to integrate effectively with the specific physical condition and technology solutions provided in DEMO.

4. Role and objectives

The role of DTT project in the frame of European fusion research

The development of a reliable solution for the power and particle exhaust in a fusion reactor is recognized as one of the major challenges towards the realization of a fusion power plant [1].

The solution to adopt a conventional divertor (which will be tested in ITER) could not be extrapolated to DEMO. In order to mitigate the risk, alternative solutions must be developed.

While several alternatives, such as the cooled liquid Li limiter in FTU [4], the Super-X divertor in MAST-U [5] or the Snowflake divertor in TCV [6] are being investigated in presently operating tokamaks, the extrapolation from present devices to DEMO is considered not reliable [1].

DTT project is part of the general European programme in fusion research, which, actually, includes many other R&D issues (plasma experiments, modeling tools, technological developments for liquid divertors, etc…).

The specific role of the DTT facility is to bridge the gap between today's proof-of-principle experiments and the DEMO reactor. DTT should, in particular, have the capability to bring such solutions to a sufficient level of maturity and integration from both physics and technology points of view.

The main objectives of the project DTT

The DTT facility will be able to test the physical and technological feasibility of various alternative divertor concepts that can confidently be extrapolated to DEMO. In this way it will possible to integrate the knowledge about the concepts of a number of divertor presently in testing operation on existing machines, with the implementation requirements of DEMO.

The main objectives of DTT, as reported in a number of official European documents [1], [7], can be summarized as follows:

- demonstrate that the heat exhaust system proposed for DEMO is able to withstand the strong thermal load acting if the fraction of radiated power turns out to be lower than expected;

- improve the experimental knowledge in the heat exhaust scientific area that cannot be addressed by present devices;
- demonstrate that the possible (alternative or complementary) divertor solutions (e.g., advanced divertor configurations or liquid metals) can be integrated in a DEMO device.

In particular it will be possible to assess whether:

- the alternative divertor magnetic configurations are viable in terms of the exhaust problems as well as of the plasma bulk performances;
- the alternative divertor magnetic configurations are viable in terms of poloidal coils constraint (i.e., currents, forces,…);
- the various possible divertor concepts are compatible with the technological constraints of DEMO;
- the divertors based on the use of liquid metals are compatible with the characteristics of the edge of a thermonuclear plasma;
- liquid metals are applicable to DEMO.

5. DTT Proposal

Motivation and context of DTT proposal

EUROfusion, the European Consortium for the Development of Fusion Energy, manages European fusion research activities on behalf of EURATOM. A significant part of the work programme of EUROfusion is devoted to the activities related to DTT.

Two projects (Work Packages) of the 2014-2018 EUROfusion work plan are focused on the study of alternative power exhaust solutions for DEMO. The funds allocated for these studies amount to over 60 MEuro in five years.

Italy plays a significant role in international nuclear fusion research. Its credibility has been more and more strengthened thanks to coordinated efforts among universities, research institutions and industries, based on attention to the innovative aspects; this cooperation has resulted in a virtuous circle that can contribute greatly to the development of the nation.

Italian fusion research is carried out inside labs 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).

The research institutions that mainly contribute to fusion research in Italy are 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 (including Università di Napoli Federico II, Seconda Università di Napoli, Università di Cassino and Lazio Meridionale), INFN with its labs in Legnaro, together with the important contributions of a number of other Italian Universities (Politecnici di Torino and Milano, Università di Milano Bicocca, Roma "La Sapienza", Roma "Tor Vergata" e Roma Tre; Cagliari, Catania, Palermo, Pisa and Tuscia). The research groups operating in such institutions have cooperated for many years as part of the EURATOM-ENEA Association and EFDA. Since 2014, the collaboration takes place within the EUROfusion Consortium Agreement.

From the experimental point of view, it is to note the significant results achieved both in Frascati by the FTU Tokamak (born as an upgrade of the FT tokamak, which held the world record of the fusion performance parameter for years, and now is one of the few large facility for liquid lithium plasma facing components) and Padua with RFX-mod (the unique device able to explore, thanks to a sophisticated magnetic feedback system, the Reversed Field Pinch configurations at plasma currents up to 2MA).

Italian researchers also gave a significant contribution to the design and experimental operation of JET in Culham and are significantly contributing, since its starting, to the design and construction of ITER.

Italy is also engaged in the construction, in Padua, of an experimental apparatus, in 1:1 scale, for the injectors of neutrals in ITER. Italian researchers, meanwhile, play a key role in the European "Fusion Road Map", leading several projects (Tasks and Work Packages) in the Horizon 2020 Work programme.

Finally, it should be pointed the high level of integration between national laboratories and the Italian industry, thanks to which a large part of the industrial contracts (around 60%) for the construction of ITER have been auctioned to the Italian companies.

Given the extent and incisiveness of fusion research in Italy and taking into account that the removal of heat is the most important challenge for the construction of a magnetic confinement fusion reactor, the Italian Government proposed to allocate specific funds for the construction of an experiment dedicated to these problems.

The proposal, with a budget of EUR 500, is part of all the projects selected for the so-called Juncker Plane (EFSI) supplied with 315 billion Euro:

(http://www.eib.org/about/invest-eu/index.htm;
http://ec.europa.eu/priorities/jobs-growth-investment/plan/docs/project-list_part-1_en.pdf;

http://ec.europa.eu/priorities/jobs-growth-investment/plan/index_en.htm).

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 were carried out in a truly European framework with WPDTT1 and WPDTT2 of the EUROfusion programme.

The relevance of the DTT project is as greater as closer it approaches to parameters and dimensions of DEMO. However, the size and the consequent construction of the project must be, in any case, compatible with the time constraints of the Road Map. This document shows that DTT can achieve its goals with a budget of 500 MEUR (funds requested by the Italian government), in addition to the financial resources allocated to WorkPakage WPDTT2 of EUROfusion in the five-year period 2014-2018

DTT parameters

Aim of DTT is to be a reduced size model of DEMO, able to study the problems of the "Scrape Off Layer" (SOL): to this spirit, every design choice has been conformed.

A machine with a plasma major radius of approximately 2.15 m is able to ensure a region of the divertor sufficiently broad to allow the testing of different magnetic configurations and various materials, including metals liquids.

The relatively high toroidal field (B_T=6T) will give the possibility to achieve plasma performances (mainly measured by the ratio between power and major radius of about 15 MW/m) not far from those in DEMO

The detailed engineering design will be the result of an international collaboration for which a strong contribution from various European laboratories is expected.

6. Scientific program

The scientific programme is described in Chapter 3 of the report " DTT Divertor Tokamak Test facility. Project Proposal" published by ENEA in July 2015, ISBN: 978-88-8286-318-0 (hereinafter also referred to as "DTT Report").

A first phase will be aimed at the realization and installation of the various components of the machine. In a subsequent phase about a year and a half long, the machine will reach the operative capability in modality robust H-mode (i.e. operating regimes characterized by configurations of single-null divertor type, top performance and with all the additional power installed).

The next phases will be reserved to test a number of alternative divertor solutions, including new magnetic configurations and innovative technologies in the liquid metal.

DTT will be equipped with a set of external poloidal coils able to guarantee a wide range of different magnetic configurations, including XD configurations [8], Snowflakes configurations (SF) [9] and double-null point (Fig. 5).

The system also includes a number of small poloidal magnetic coils internal to the vacuum chamber, which, among other things, allow to modify locally the magnetic configurations in the divertor area.

The Fig. 6a shows the poloidal section of DTT, including the poloidal system; the plasma is characterized by a "Single Null" equilibrium, high β, a Ip = 6 MA current. Varying the current in the small bottom coils (highest total current about 50kA each) allows producing the different magnetic topologies reported in the central and right picture. In Figure 6b a configuration "quasi-SF" is shown, with XD characteristics; Fig. 6c shows instead a particular configuration characterized by a wide area with low and uniform poloidal magnetic field.

A large space is allocated at the bottom of the machine to allow a easy installation of a divertor realized by using liquid metal technology [10].

The poloidal system is designed to have plasmas even with double null configurations.

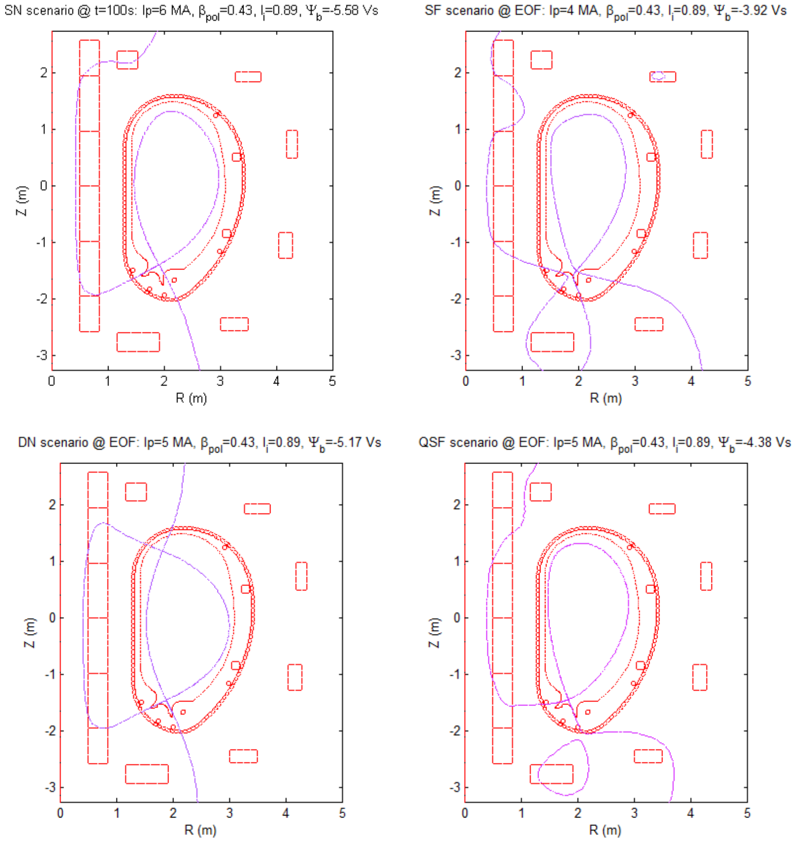
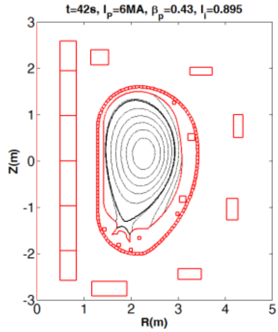


Figure 5: Conventional and alternatives magnetic configurations that can be realized by the DTT poloidal field system.

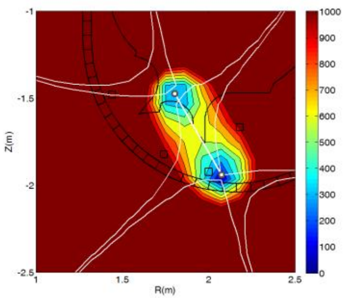
All the external coils (including the toroidal one) are designed by using superconductor technology; in this way discharges lasting around 100s are allowed, only limited by the plasma resistive flux consumption if assuming no external current drive. The heating system is based on a set of combined different technologies; a possible actual solution may provide about 15MW ECRH (Electron Cyclotron Radiofrequency Heating) at 170 GHz; some 15MW ICRH (Ion Cyclotron Radiofrequency Heating) at 60-90 MHz; about 15MW NBI (Neutral Beam Injection).

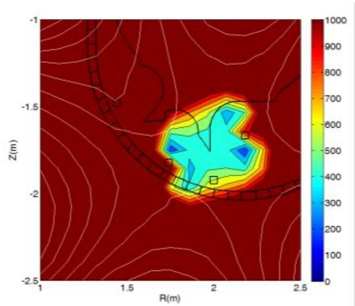
The final decision will be taken in a later stage of the scientific program (further details are in Chapter 3 of the aforementioned DTT Report).

The ambitious program of DTT is spread over a period of several years. During the initial plasma operations 15 MW of ICRH and 10 MW of ECRH will be available. Additional power, up to a total of 45 MW, will be afterwards installed, taking also advantage of actual technologies available in the various phases of the project. The project foresees the testing of different divertor concepts looking for the best magnetic configuration and the optimized divertor design; as an additional goal, also the solution based on the technology of liquid metal will be optimized



(a)





(b) *(c)*

Figure 6: a) Standard "Single Null" equilibrium (SN, with just one X point); b) Configuration with two neighboring null points and related XD configuration (with magnetic flux expanding on the divertor plates); c) "Snowflake" configuration (SF) with a wide region charcterized by a low poloidal magnetic field value.

7. Physics basis of the project and its operational capabilities

An artist's view of the DTT facility is reported in Figure 7: Artist's view of the DTT device.

All the plasma configurations (including standard single null and advanced configurations) satisfy the following constraints:

- distance not less of 40 mm between the plasma last closed surface and the first wall, in order to minimize the interaction between the plasma and the vacuum chamber; as a matter of fact (see Chapter 3 of the aforementioned DTT Report) the power decay length at 6 MA is about 2 mm at the outboard midplane;
- plasma shape parameters similar to those of the present design of DEMO: $R/a \approx 3.1$, $k \approx 1.76$, $<\delta> \approx 0.35$;
- pulse lasting more than 100 s (total available flux about 45 Vs, Central Solenoid swing about 35 Vs).

These needs have suggested the use of superconducting windings; in particular the magnetic system includes:

- Toroidal Field (TF) magnetic system: 18 TF coils; B_{peak}: 12.0 T, B_{plasma}: 6.0 T, 65 MAt;
- Central Solenoid (CS): 6 CS coils: B_{peak}; 12.5 T; available poloidal flux: $\pm$17.6 Vs;
- Poloidal Field (PF) magnetic system: 6 PF coils; B_{peak}: 4.0 T.

The PF system also includes eight copper in-vessel coils; in particular:

- two in-vessel coil for radial and vertical stabilization and control;
- four out of six in-vessel coil for magnetic control of SOL and strike point sweeping.

To pursue the aims of the program, particular attention has been devoted to the diagnostics and control issues, especially those relevant for plasma control in the divertor region, anyway having in mind the requirement of a strong compatibility with the operating conditions in DEMO.

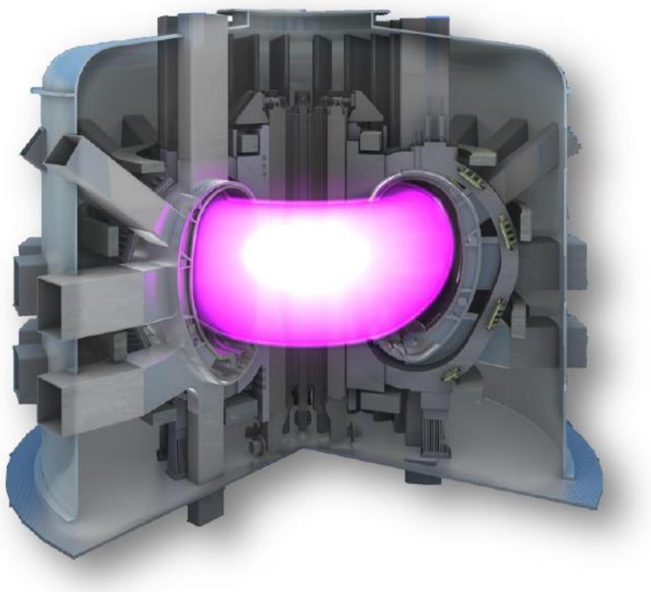


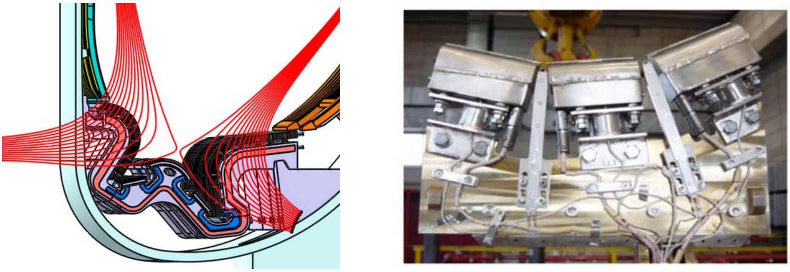
Figure 7: Artist's view of the DTT device.

The design of the Vacuum Vessel (VV) includes a wall of INCONEL 625. The 18 sectors are joined by welding. The maximum thickness of the shell is 35 mm, while the 5 ports per sector are 25 mm thick.

The first wall consists of a bundle of tubes armored with plasma-sprayed tungsten. The layer of tungsten is about 5 mm thick; the bundle of cooling copper tubes has a thickness of 30 mm, and the support is provided by a back plate of SS316LN steel, 30 mm thick.

The main goal of the DTT project is to test several divertor concepts and configurations. Therefore the design of the VV, the ports and the additional heating system takes into account the constraints related to the testing of diverters liquid metal.

The “first day” design includes a tungsten divertor, realized with W-shaped modules, distributed along the VV; the design is fully compatible with advanced magnetic configurations (Fig. 8).



(a) *(b)*

Figure 8: a) A possible tungsten divertor, compatible with both the SN and SF configurations; b) Liquid lithium limiter installed FTU: a good starting point for developing a liquid lithium divertor.

8. Costs and schedule

The facility needs to be ready in the early 2020s, in order to be able to bring at least one alternative divertor strategy to a suitable level of maturity by 2030 for a positive decision on DEMO. The nominal duration of the construction of DTT from the "green light" to the beginning of the initial operational phase is expected in about seven years. Consistently with EUROfusion road map, a reasonable time planning implies that the first tenders for the supply of DTT components could be issued by 2016.

The realization of the DTT project is a top priority for the world of European research, since it represents a crucial step towards the realization of a DEMO reactor.

The DTT scientific program was included in the list of projects submitted for funding of 500 million Euro as part of the "Program Juncker" of 315 billion Euro (EFSI: European Fund for Strategic Investments). The amount claimed is consistent with the table of costs of DTT reported, in summary form, in Tab. I and, in more detail, in Chapter 5 of the aforementioned DTT Report.

Table I
DTT Cost Breakdown (Summary)

Items	Costs (M€)
Components and Parts	209
Magnet power supplies	60
Additional heating	92
Remote Handling and cooling system	37
Diagnostics & control	11
Infrastructures	25
Assembly on site	10
Contingency	25
Personnel	30
TOTAL	499

9. Site assessment and socio-economic Impacts

The choice of the site should take into account the mission of DTT as "European facility". In this perspective, significant elements for the selection of the site are the accessibility and the scientific attractiveness for staff (scientists and engineers) that, coming from many European countries and beyond, will carry out the construction and promote experimentation.

Chapter 5 of the aforementioned DTT Report, shows the feasibility and robustness of the possible, but non exclusive, choice of the site in the area of ENEA in Frascati (Rome, Italy). It indeed responds to various specifications of the location from the start of the planned construction in 2016 and also is a quite cultural and logistic attractive site for the European scientific community.

The realization of the project will be beneficial also from other points of view, such as:

- socio-economic aspects of the hosting territory;
- from the technological and scientific challenges for the EU fusion community, which will have the occasion to gain experience by building and operating a European DEMO-relevant machine in the next decades.

In fact, a well consolidated experience in recent decades shows that the realization of big international research projects has a large and positive impact on the socio-economic hosting territory; consider, for example, the impact of JET and, more recently, that of the design and construction of ITER. Construction of major research infrastructure provides an opportunity to use the increase in knowledge as a driving force for the development of synergistic technical and economic aspects of the surrounding area. Extrapolating from the experience, it is possible to provide a number of positive elements expected for the surrounding area, during both the construction and the operations phases. The list of main effects includes: i) occupational impact; ii) technology transfer to the industry; iii) positive economic impact on businesses and, in general, on the level of welfare of the population; iv) the transfer of knowledge and innovation capacity in favor of scientific laboratories and universities in the area.

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