A volte non sono aeroplani ... : la roadmap europea verso il reattore a fusione nucleare con i progetti DTT, ITER e DEMO

Associazione Ingegneri Aeronautici e Aerospaziali
ex Allievi dell'Università degli Studi di Napoli Federico II
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(2) Consorzio CREATE, Napoli
(3) Università degli Studi della Campania

Sommario

Parte I
Raffaele Albanese

- Ingegneri aeronautici/aerospaziali nella fusione nucleare
- Introduzione alla fusione termonucleare controllata
- Roadmap europea della fusione
- Progetto DTT
- Attività del Consorzio CREATE

Parte II
Massimiliano Mattei

- …

Ingegneri aeronautici/aerospaziali nella fusione nucleare …

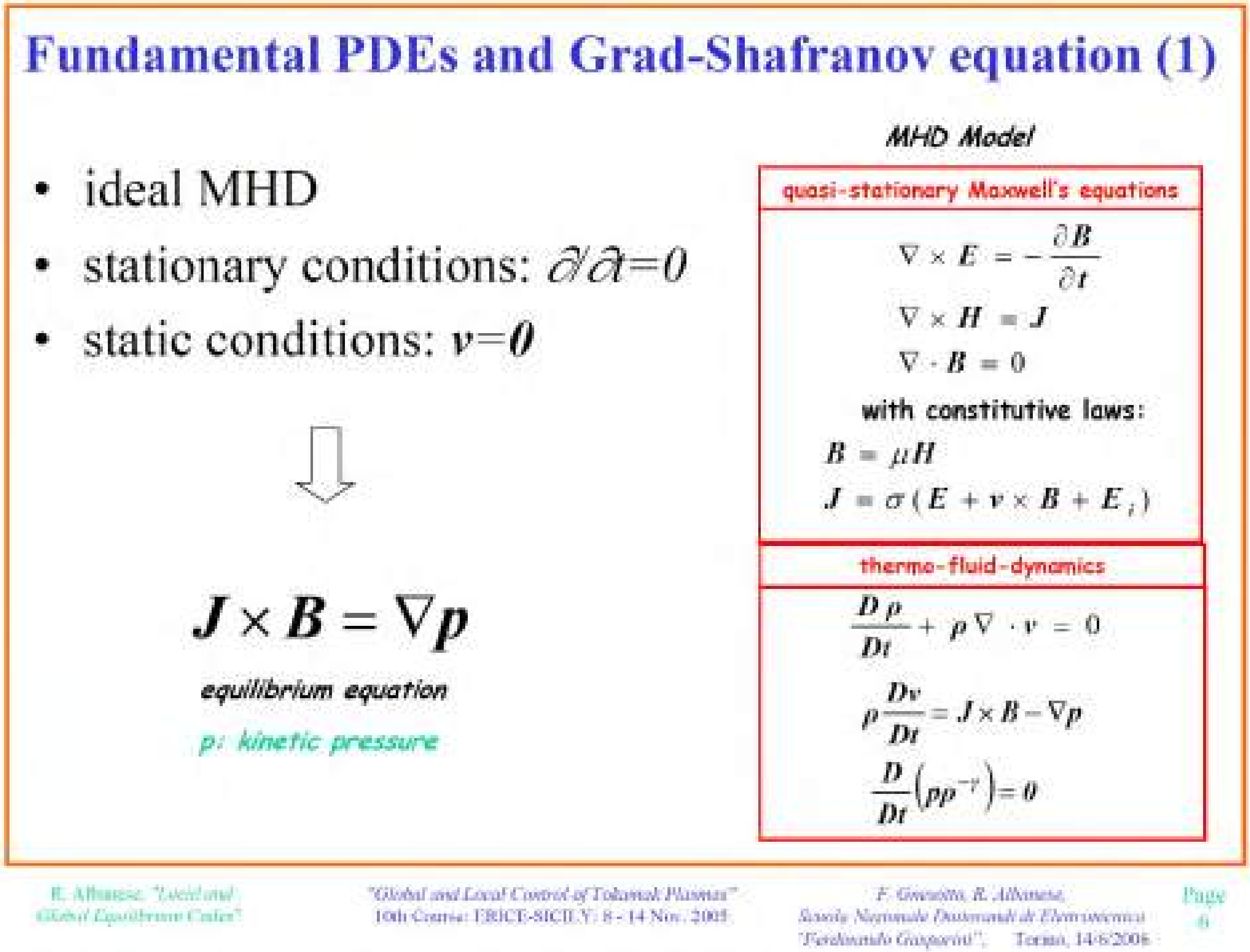
- La mia storia personale: ad inizio anni ’80, neolaureato in Ingegneria Aeronautica, mi hanno lanciato nel settore della fusione nucleare i Proff. Bobbio e Meola:

Scipione BOBBIO
Ordinario di Elettrotecnica
Univ. Napoli
scomparso nel 2000

Carlo MEOLA
Ordinario di Fluidodinamica Numerica
Univ. Napoli
Socio Onorario AIAN

Ingegneri aeronautici/aerospaziali nella fusione nucleare …

- **Dalla fluidodinamica alla *magneto*fluidodinamica (MHD)**



Fundamental PDEs and Grad-Shafranov equation (1)

- ideal MHD
- stationary conditions: $\partial/\partial t=0$
- static conditions: $v=0$

⇩

$$J \times B = \nabla p$$

equilibrium equation

p: kinetic pressure

MHD Model

quasi-stationary Maxwell's equations

$$\nabla \times E = -\frac{\partial B}{\partial t}$$
$$\nabla \times H = J$$
$$\nabla \cdot B = 0$$

with constitutive laws:

$$B = \mu H$$
$$J = \sigma (E + v \times B + E_i)$$

thermo-fluid-dynamics

$$\frac{D\rho}{Dt} + \rho \nabla \cdot v = 0$$
$$\rho \frac{Dv}{Dt} = J \times B - \nabla p$$
$$\frac{D}{Dt}\left(p \rho^{-\gamma}\right) = 0$$

R. Albanese, "Local and Global Equilibrium Codes"

"Global and Local Control of Tokamak Plasmas"
10th Course: ERICE-SICILY: 8 - 14 Nov. 2005

F. Gnesotto, R. Albanese,
Scuola Nazionale Dottorandi di Elettrotecnica
"Ferdinando Gasperini", Torino, 14/6/2006

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6

Nel caso particolare dell'equilibrio MHD si ha:

$$J \times B = \nabla p$$

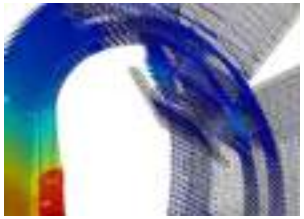
e quindi

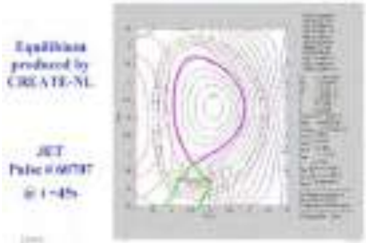
$$(\nabla \times B) \times B = \mu_0 \nabla p$$

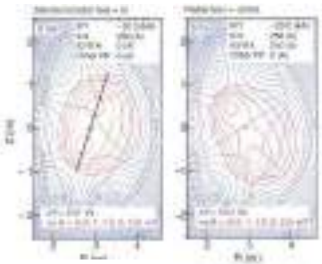
con implicazioni analoghe a quelle che vediamo in aerodinamica (Crocco, Kutta-Joukowski)

Ingegneri aeronautici/aerospaziali nella fusione nucleare …

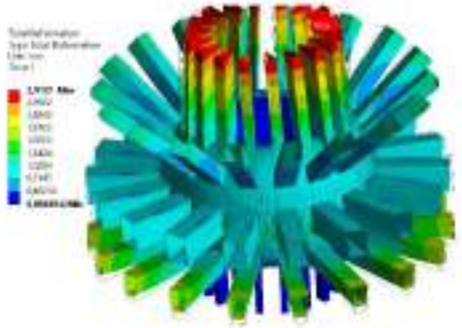
- **Dalla fluidodinamica numerica ai modelli numerici per *campi e circuiti:***
  - *Formulazioni differenziali ed integrali per il calcolo di campi elettromagnetici 2D e 3D*
  - *Analisi di problemi accoppiati (modello MHD)*
  - *Problemi inversi (identificazione ed ottimizzazione)*
  - …







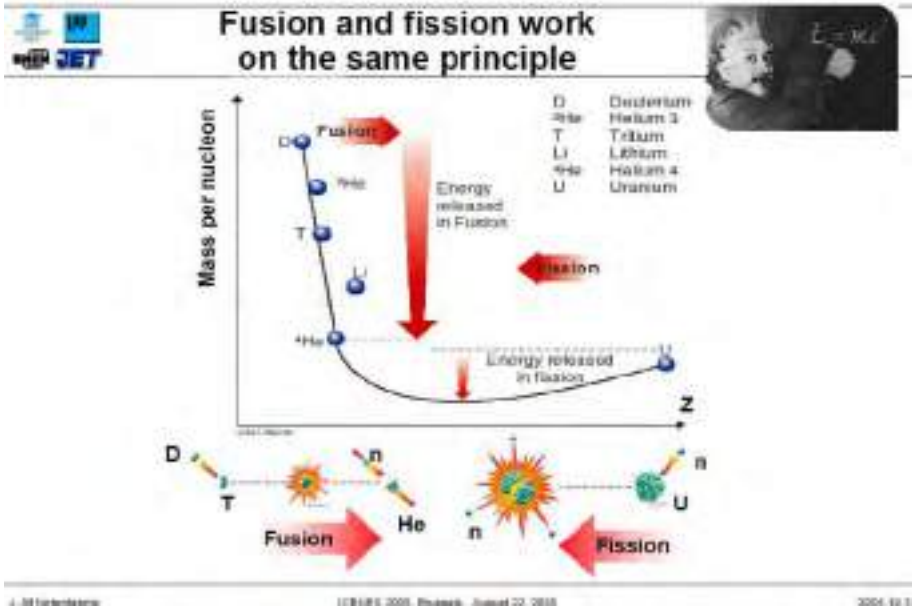
- ***… ed altre tematiche cui possiamo contribuire a pieno titolo:***
  - *Termofluidodinamica*
  - *Pompaggio*
  - *Elettromeccanica*
  - *Analisi strutturali ed a fatica*
  - …



ENEA Member of EUROfusion

AIAN

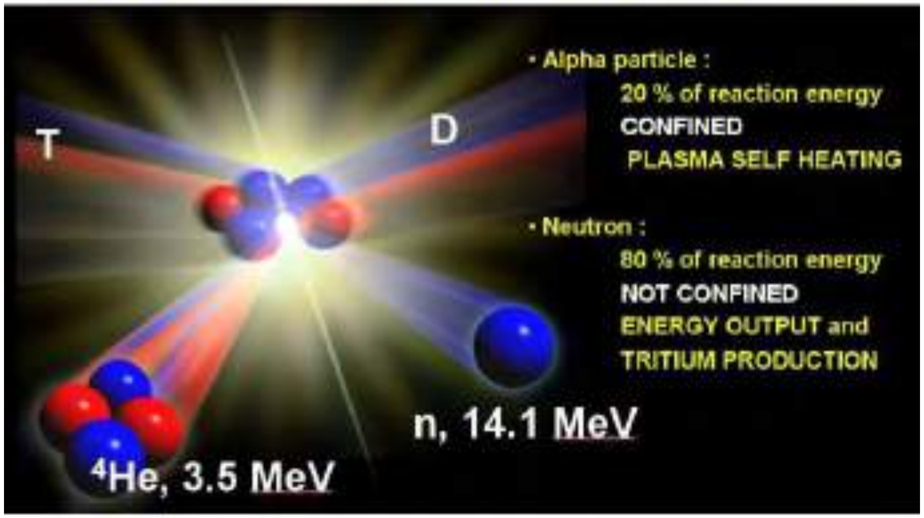
Introduction: Fusion vs fission



Fusion and fission work on the same principle

$$\Delta E = \Delta m\, c^2$$

D-T Fusion Reaction: $D + T \rightarrow {}^4He + n$

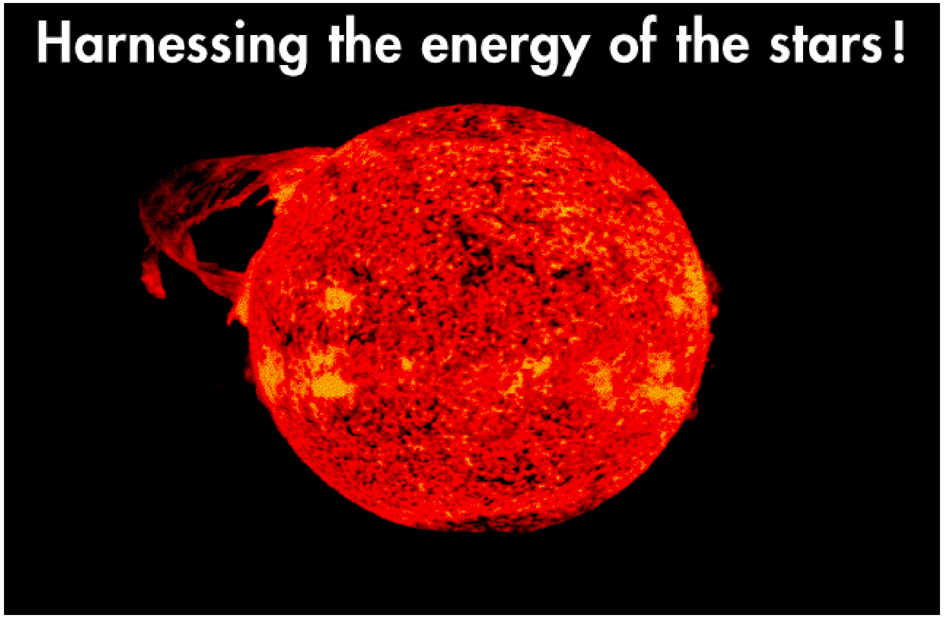


- Alpha particle :
  20 % of reaction energy
  CONFINED
  PLASMA SELF HEATING
- Neutron :
  80 % of reaction energy
  NOT CONFINED
  ENERGY OUTPUT and
  TRITIUM PRODUCTION

Advantages of fusion:

- Abundance of fuel
- Small amount of fuel needed for reactor conditions
- No pollution
- No greenhouse effect
- No direct nuclear waste
- No risk of severe accidents

Introduction: The plasma

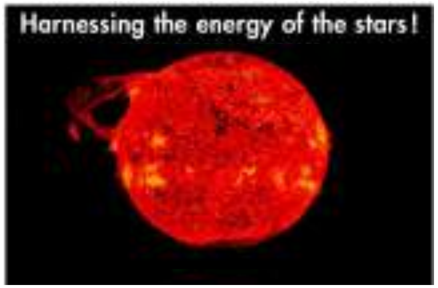


At the very high temperatures needed for fusion the gas is fully *ionized* and is a very good conductor: *plasma* (4th state of the matter).

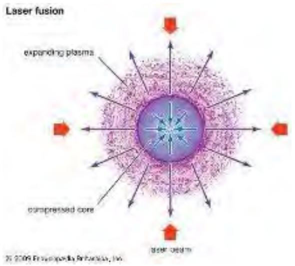
Introduction: Fusion on Earth

Ignition condition:

$n\cdot T\cdot\tau \geq 5\times10^{21}\ m^{-3}\ s\ KeV$



Gravitational confinement

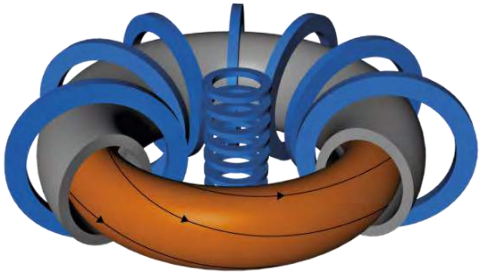


Inertial confinement

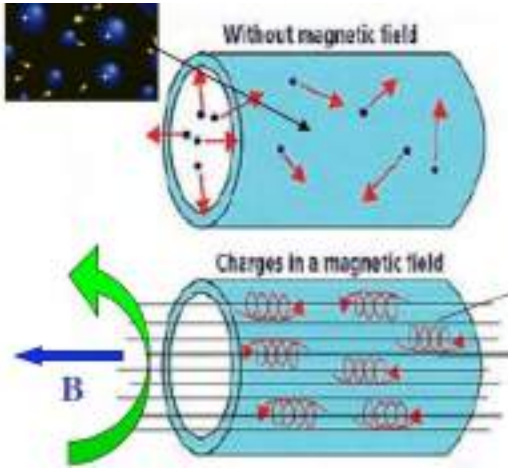
In the 90s the JET Tokamak achieved:

$n\cdot T\cdot\tau = 0.9\times10^{21}\ m^{-3}\ s\ KeV$

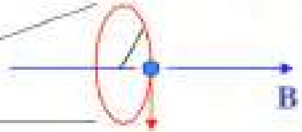
$Q = P_{fus}/P_{in} = (16MW/25MW) = 0.6$



Magnetic confinement



$$r_L = \frac{v_\perp}{\Omega} \propto \frac{(m\,T)^{1/2}}{B}$$



Larmor radius

^2H, $T = 10$ keV, $B = 5$ T

$r_{Li} = 0.14$ cm

$r_{Le} = 5\times10^{-3}$ cm

Introduction: Tokamaks

Tokamaks are among the most complex machines ever conceived by the mankind:

- **Coexistence of temperatures close to highest and lowest values in the universe**
- **Nuclear environment, high magnetic fields, vacuum requirements, large heat fluxes**
- **All fields of science and engineering involved: large teams needed**

Wesson J., "Tokamak", Oxford University Press 2011 – 4th Edition

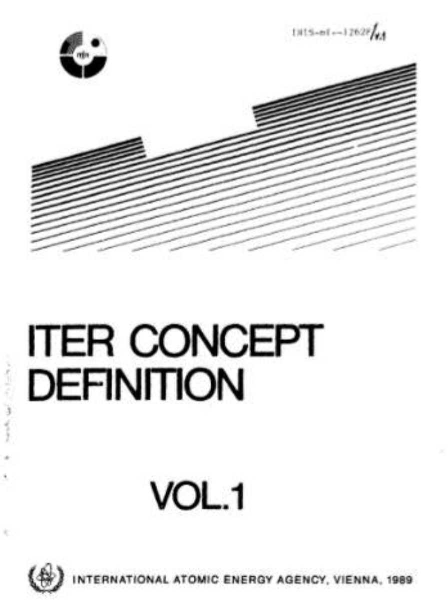
The JET project

design proposal

NEXT EUROPEAN TORUS

STATUS REPORT

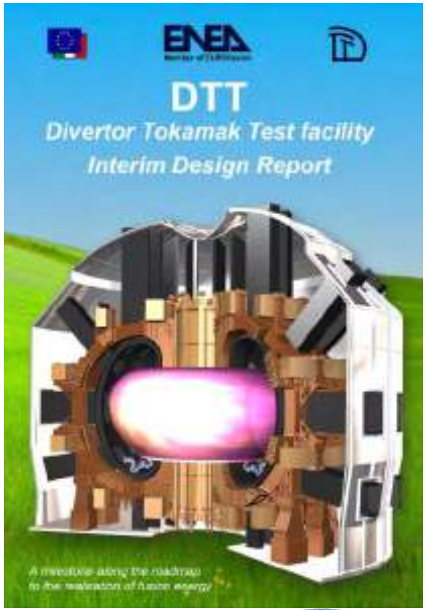
DECEMBER 1985



ITER CONCEPT DEFINITION

VOL.1

INTERNATIONAL ATOMIC ENERGY AGENCY, VIENNA, 1989



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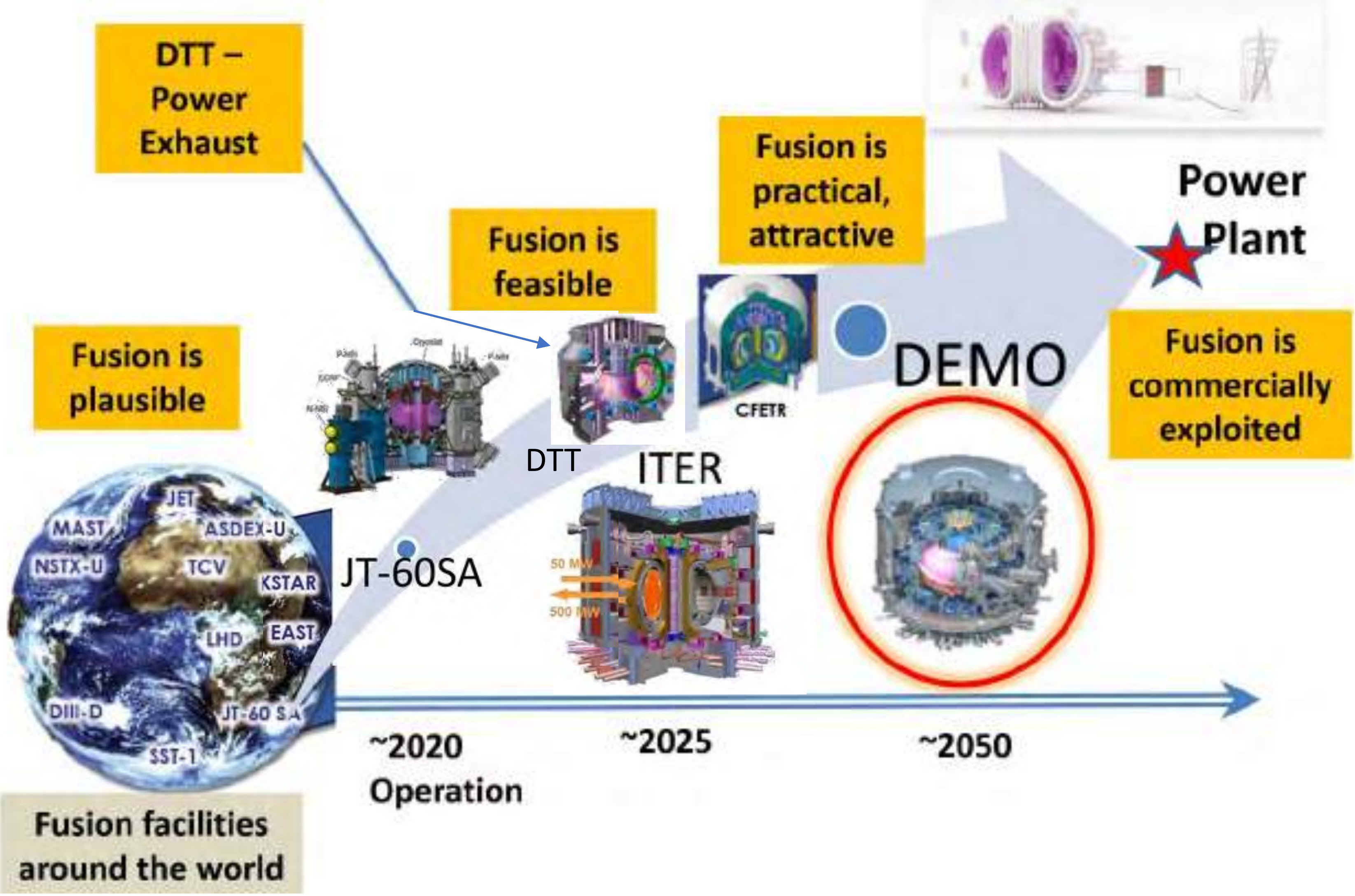
DTT

Divertor Tokamak Test facility

Interim Design Report

Fusion Roadmap: facilities around the world



DTT – Power Exhaust

Fusion is plausible

Fusion is feasible

Fusion is practical, attractive

Power Plant

Fusion is commercially exploited

~2020 Operation

~2025

~2050

Fusion facilities around the world

Fusion Roadmap: timeline

- **In the 90's the JET tokamak** achieved one produced **16 MW of nuclear fusion power** from D-T reactions, with about 25 MW of input heating power, i.e., with a fusion gain **Q>0.6**.

- To improve Q, the current strategy aims to increase magnetic field, plasma current and machine dimensions. This is the mission of ITER, an international tokamak conceived in the 80's under construction at Cadarache, France. The first plasma is expected in 2025. In the next decades ITER should produce $P_{fus}=500$ MW from $P_{in}=50$ MW with $Q\approx10$.

- ITER prepares the way for electricity commercial production to the grid by fusion. The EU Roadmap proposes a strategic vision toward the generation of electrical power by a Demonstration Fusion Power Plant (DEMO) to be completed in the second half of this century.

Fusion Roadmap: EU strategy

European Research Roadmap
to the Realisation of Fusion Energy

EUROfusion

The European fusion community identified eight important missions on the path towards fusion electricity:

1) Plasma regime of operation

2) Heat-exhaust system

3) Neutron resistant materials

4) Tritium self-sufficiency

5) Implementation of intrinsic safety features of fusion

6) Integrated DEMO design and system development

7) Competitive cost of electricity

8) Stellarator

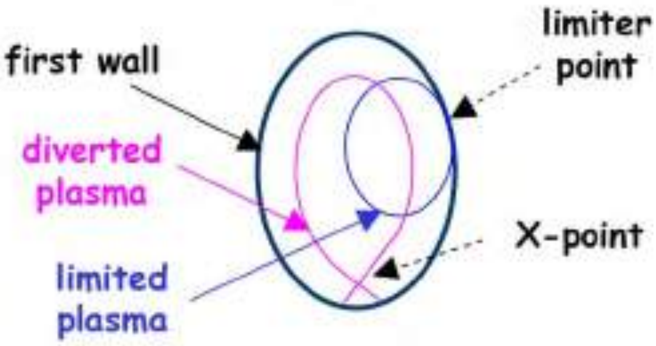
"If alternate exhaust strategies were to be only explored in the event of ITER showing that the baseline exhaust strategy cannot be extrapolated to DEMO, the realisation of fusion would be delayed by at least 10 years…. for the alternative approaches the extrapolation from proof-of-principle devices to DEMO based on modelling alone is considered too large. If a promising alternative concept emerges, a divertor optimised for the concept will be implemented in the Italian Divertor Test Tokamak (I-DTT) facility as a joint European collaboration. "

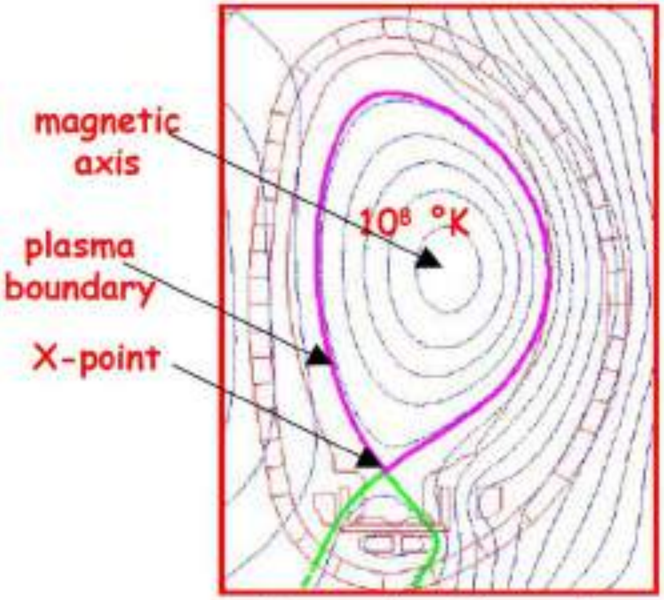
Tony Donné, William Morris, et al., "European Research Roadmap to the Realisation of Fusion Energy A road map to the realisation of fusion energy" www.euro-fusion.org/fileadmin/user_upload/EUROfusion/Documents/2018_TopLevel_Roadmap.pdf

Fusion Roadmap: plasma edge

PLASMA BOUNDARY

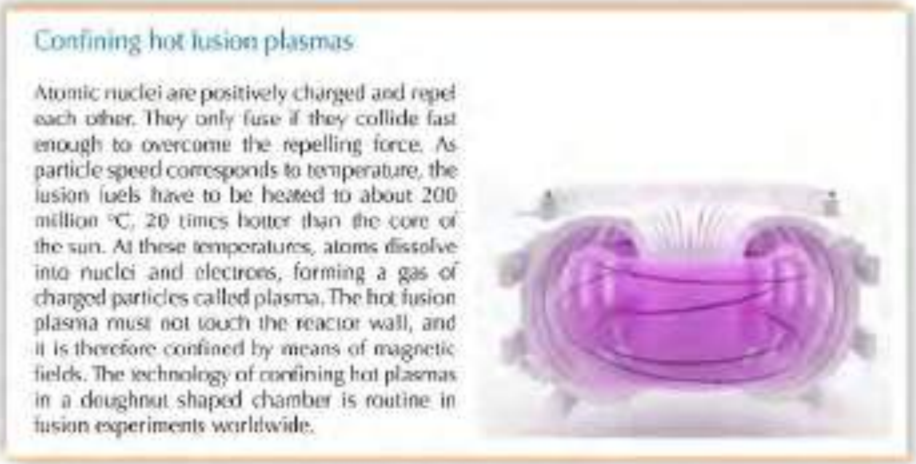
- The plasma boundary is defined as the **outermost closed magnetic surface that does not intersect solid walls**:
  - limited plasmas (the plasma core touches the wall at a *limiter point*)
  - diverted plasmas (the boundary flux is determined by the *X-point*, i.e., the magnetic null point)
- The plasma boundary is determined by both external currents and plasma current density: therefore, it is usually a result of the calculation (*free boundary problem*)





diverted configuration

Fusion Roadmap: the heat exhaust challenge



Confining hot fusion plasmas

Atomic nuclei are positively charged and repel each other. They only fuse if they collide fast enough to overcome the repelling force. As particle speed corresponds to temperature, the fusion fuels have to be heated to about 200 million °C, 20 times hotter than the core of the sun. At these temperatures, atoms dissolve into nuclei and electrons, forming a gas of charged particles called plasma. The hot fusion plasma must not touch the reactor wall, and it is therefore confined by means of magnetic fields. The technology of confining hot plasmas in a doughnut shaped chamber is routine in fusion experiments worldwide.

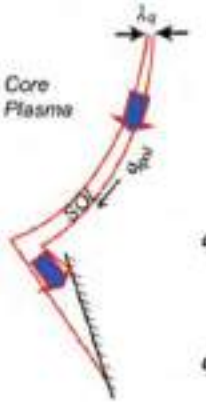
Extreme conditions:

- *in the plasma core: T > 100 M °K*
- *in the SOL: $q_{//} \approx 1$ GW/m²*

The geometry reduces it by a factor of 30:

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

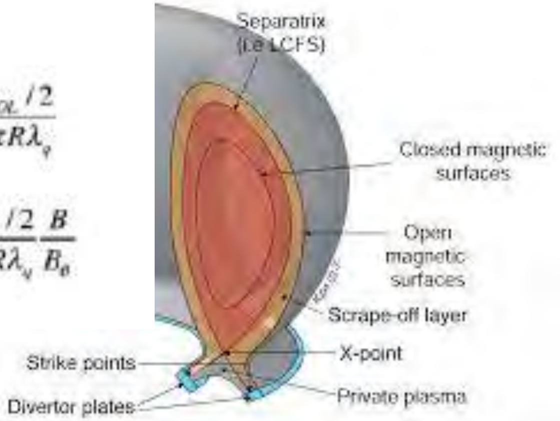
… … But the unmitigated heat flow on the plates is still higher than the current technological limits (5-10 MW/m²)

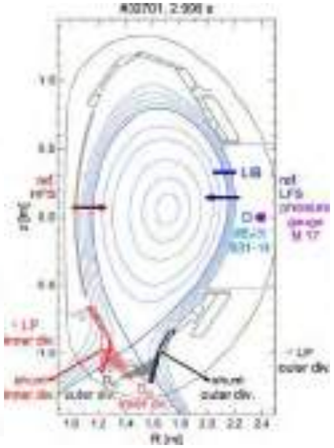


$$q_{pol} \sim \frac{P_{SOL}/2}{2\pi R\lambda_q}$$

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

Fig. 1. Power flux on the divertor.





Two-point Modeling of the Divertor SOL
P. Stangeby, Inst. for Aerosp. Studies, Toronto Univ., Ont., Canada

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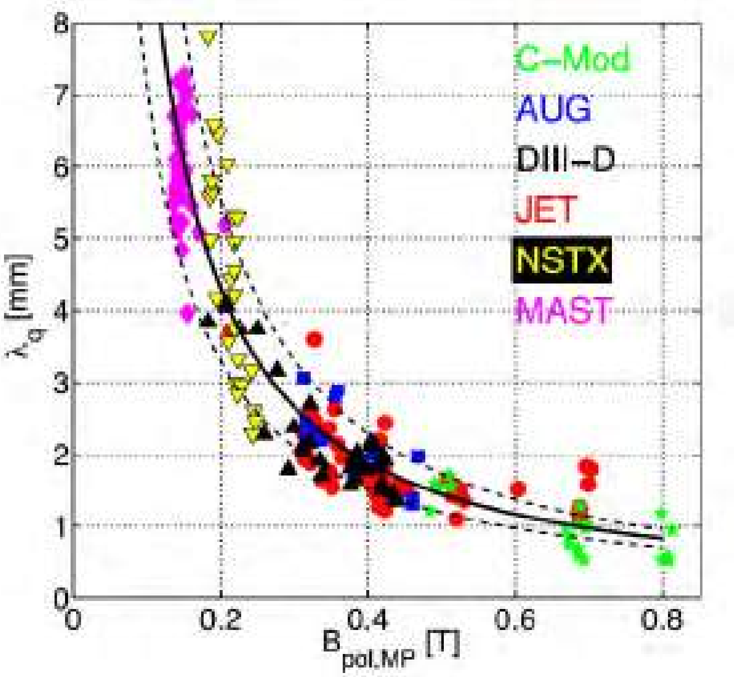
Fusion Roadmap: SOL

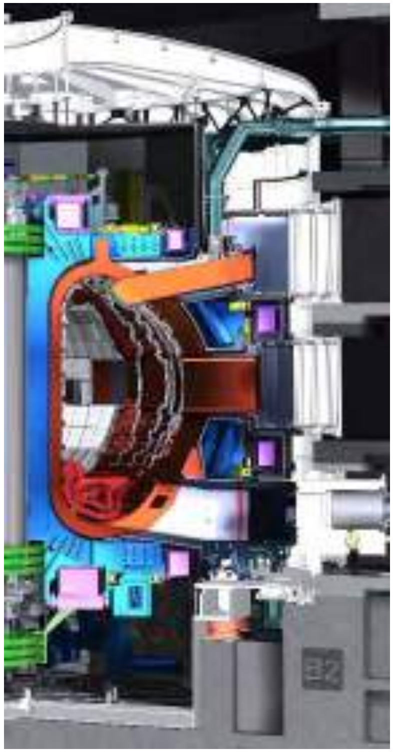
From a multimachine scaling of the upstream heat flux width the SOL power flow decay length scales as: $\lambda_q \propto B_{pol}^{-1}$ and does not depend on R

Power flux $q_\vartheta = {}^{P}/_{2\pi R\lambda_q} \propto \frac{P}{R}$

for ITER and DEMO $\lambda_q \approx 1\ mm$



T.Eich. et al. NF 53 (2013) 093031

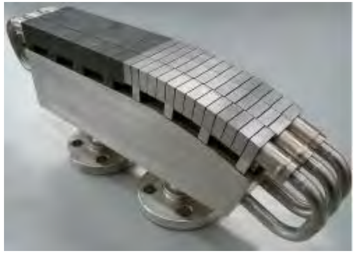


Effective surface 1-2 m^2

Power flux: tens of MW/ m^2

Fusion Roadmap: Possible solutions for heat exhaust

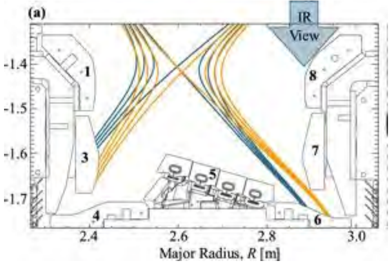
- Plasma facing components to cope with very large power fluxes
  - **10-20 MWm^{-2} achieved**



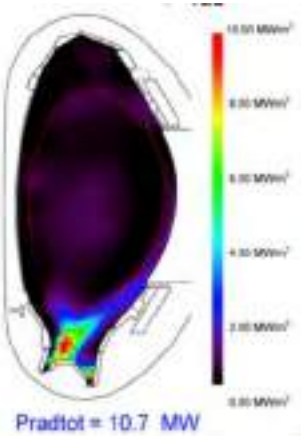
Innovative materials (Liquid Metal PFCs)

- **Geometry + plasma physics**

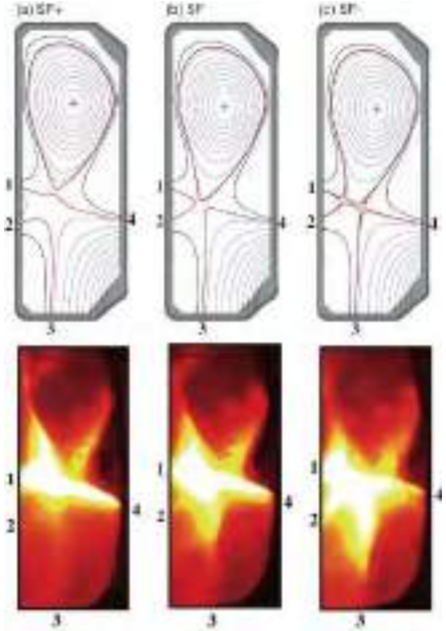
Strike point sweeping (courtesy of JET)



- **Remove plasma energy before it reaches PFCs → radiation**

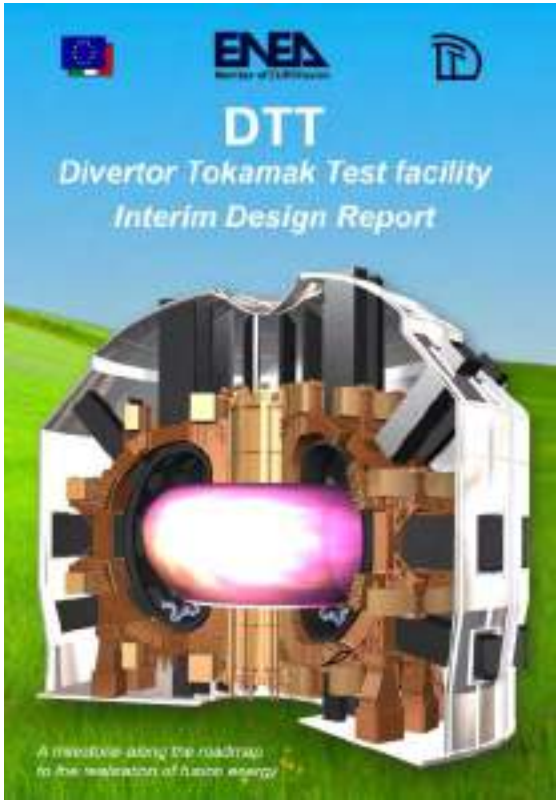


Alternative configurations (courtesy of EPFL)



DTT: Definition of role and objectives

Special Section of Fusion Engineering and Design, Vol. 122, 2017, pp. 253-294



DTT

Divertor Tokamak Test facility

Interim Design Report

https://www.dtt-project.enea.it/downloads/DTT_IDR_2019_WEB.pdf

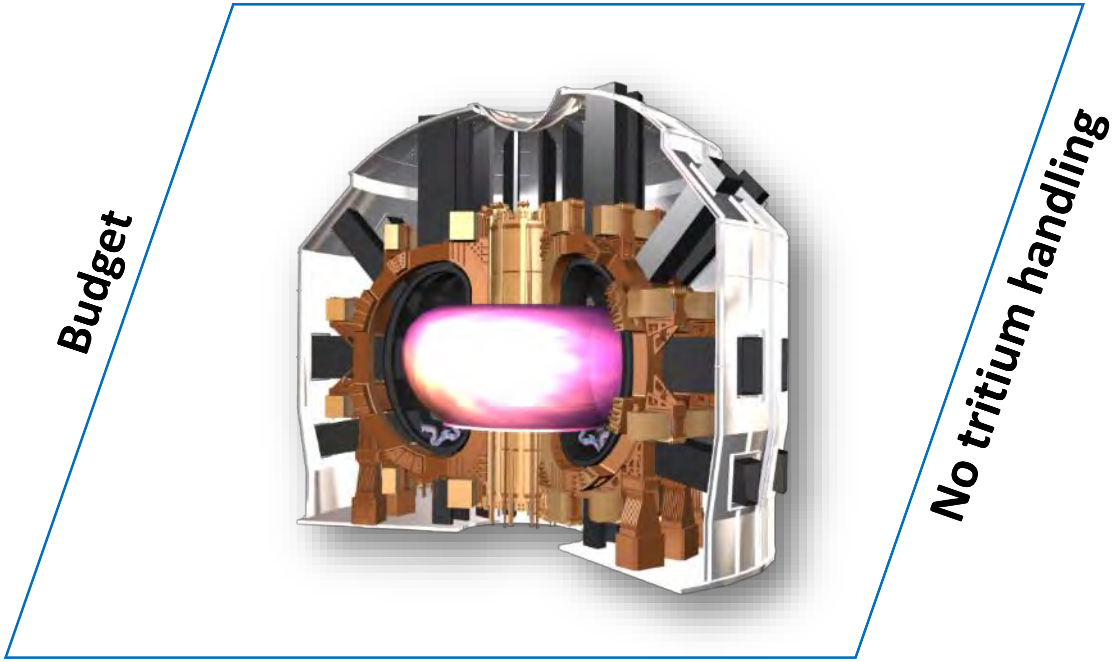
- **Explore and qualify alternative power exhaust solutions for DEMO**.
- **Test the physics and technology of various alternative divertor concepts under plasma conditions that can be extrapolated to DEMO**.
- Ultimately show whether alternative configuration or liquid metal plasma facing components are technologically viable, maintainable and economical.
- Train new generations of engineers and scientists

Advanced system design, new technological and engineering solutions:

- Superconductivity, huge heat flux, real time control, power electronics, innovative materials, RH …

DTT: Boundary conditions in the design

Physics parameters relevant for ITER/DEMO and core – edge integration



Budget

No tritium handling

Technology choices relevant for DEMO

DTT: Main parameters

Parameter	**DTT**	**ITER**	**DEMO**
Major radius R (m)	2.11	6.2	9.1
Minor radius a (m)	0.64	2.0	2.9
Plasma current Ip (MA)	5.5	15	19.6
Toroidal field B_T (T)	6.0	5.3	5.7
Plasma volume V_p (m^3)	28	853	2400
Density <n> (10^{20}m-^{3})	1.8	1.0	0.9
Greenwald fraction $\langle n \rangle / n_G$	0.42	0.85	1.2
Additional power P_{tot} (MW)	45	120	460
Confinement time τ_E (s)	0.43	3.6	4.2
Temperature <T> (keV)	6.1	8.5	13.1
Total beta β (%)	2.2	2.2	3
Normalized collisionality ν* (10^{-2})	2.6	2.3	1.4
Normalized Larmor radius ρ* (10^{-3})	2.9	2.0	1.5
P_{sep}/R (MW/m)	15	14	17
Power e-folding length λ_q (mm)	1.8	2.2	2.2
Pulse length (s)	90	400	7600

https://eneabox-dtt.enea.it/index.php/apps/files?dir=/Shared/DTT/00_Project-Integration/05_Technical_Integration/03_Plant_Integration_Documentation

DTT: requirements

Physical requirements

- Preservation of 4 DEMO relevant parameters: T_e , ν^*, Δ_d/λ_0 , β
- Relaxation on normalized Larmor radius: $\rho^*{}_x R^\varepsilon$ ➔ $\varepsilon = 0.75$
- Integrated scenarios: solutions compatible with DEMO plasma performance

Technological requirements

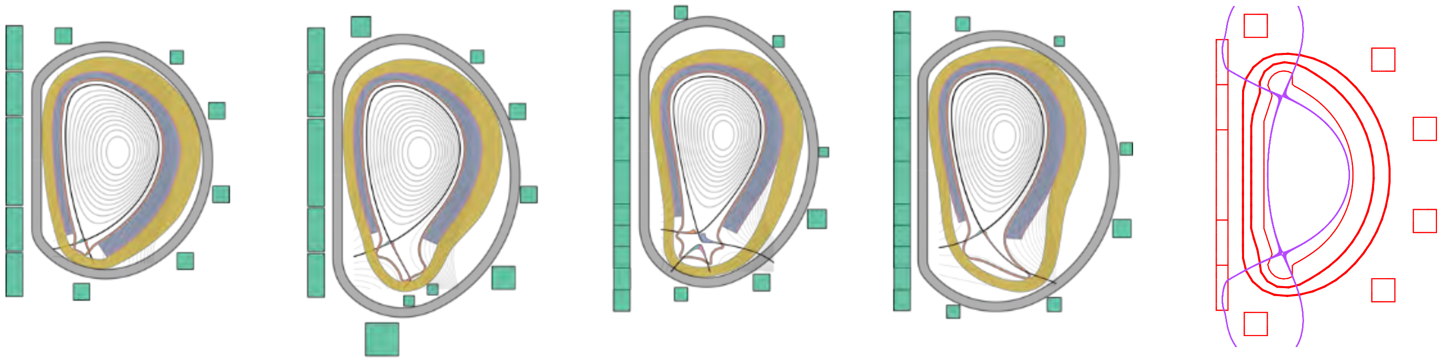
- $P_{SEP}/R \geq 15$ MW/m
- Flexibility in the divertor region ➔ test several divertors
- Possibility to test alternative magnetic configurations
- Possibility to test liquid metals
- Integrated scenarios: solutions compatible with technological constraints of DEMO
- Budget constraint: 500 M€ (as cost $\approx B^2R^3$) ➔ R_{MAX} 2.2m

no tritium handling & no blanket (even if the expected neutron flux is significant)
no significant current drive contribution

DTT: Flexibility - plasma configurations

All coils separately fed (6 in the CS, 6 PF coils). In this way DTT can get the configurations proposed for DEMO with a single PF coil system

EU DEMO (DTT1/PMI)

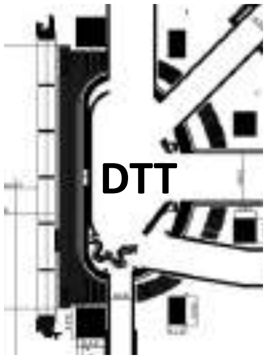

Single Null

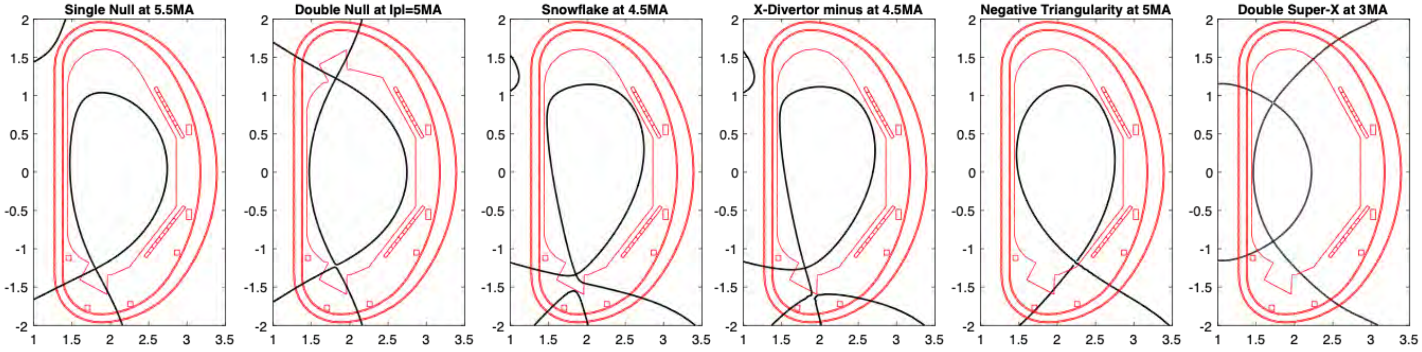
XD with internal coils

Snowflake plus and minus

Super-X with external coils

Double Null




Single Null at 5.5MA

Double Null at Ipl=5MA

Snowflake at 4.5MA

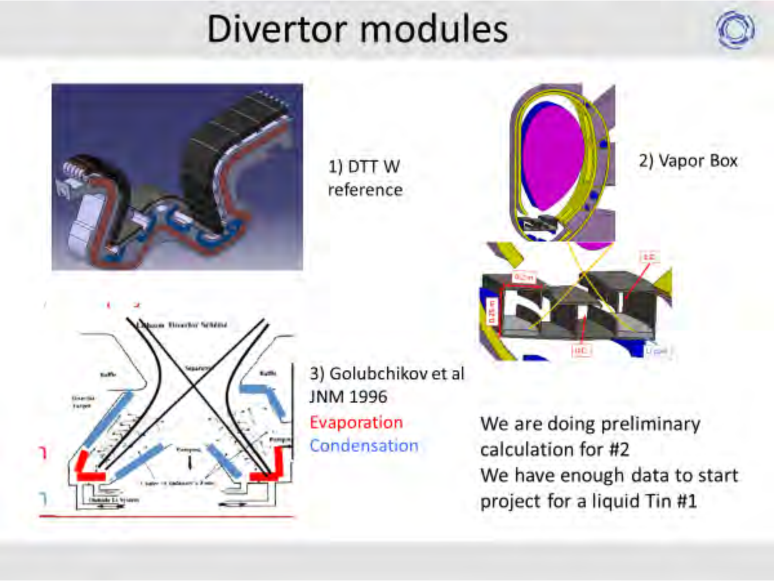
X-Divertor minus at 4.5MA

Negative Triangularity at 5MA

Double Super-X at 3MA

DTT: Flexibility - divertor

DTT makes it possible to test different divertor concepts: both conventional and advanced solutions:



Divertor modules

1) DTT W reference

2) Vapor Box

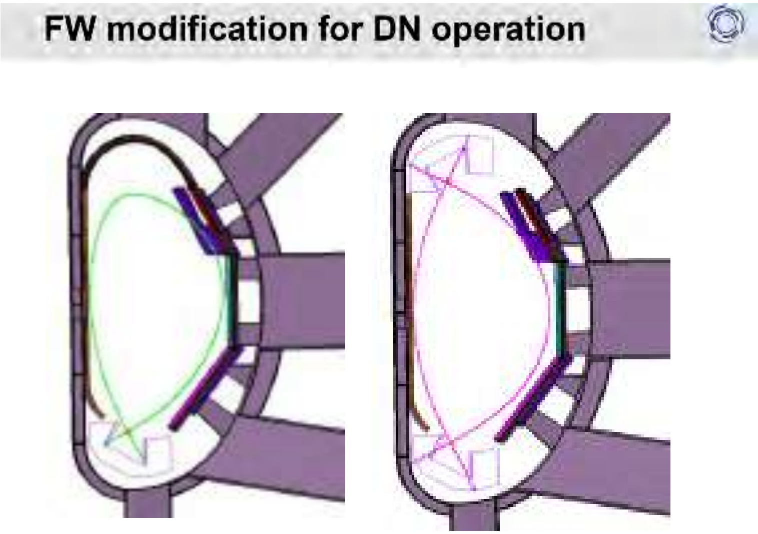
3) Golubchikov et al JNM 1996

Evaporation

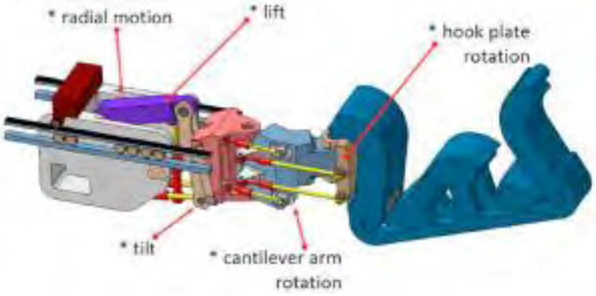
Condensation

We are doing preliminary calculation for #2

We have enough data to start project for a liquid Tin #1



FW modification for DN operation



The challenge is that the EUROfusion decision on the first divertor concept is planned around 2023 and we should be so flexible to incorporate it inside the DTT vessel

DTT: Site

9 sites were proposed from all over Italy

- “Casale Monferrato” (TO)
- “Ferrania” (SV)
- “La Spezia” (SP)
- “Porto Marghera” (VE)
- “CR ENEA Brasimone” (BO)
- “Cittadella Della Ricerca” (BR)
- **“CR ENEA Frascati” (RM)**
- “Capitolo San Matteo” (SA)
- “Manoppello” (PE)

AVVISO PUBBLICO

PER UNA SELEZIONE FINALIZZATA ALLA SCELTA DI UN SITO PER L'INSEDIAMENTO DELL' ESPERIMENTO DTT (DIVERTOR TOKAMAK TEST)

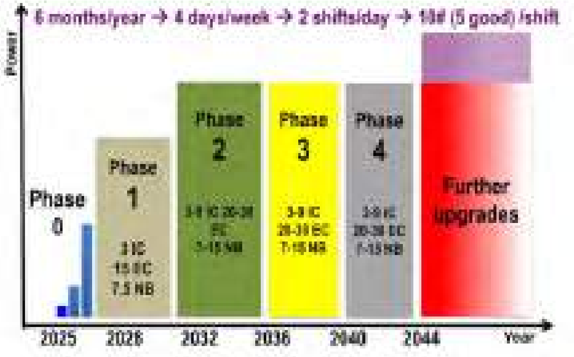
“CR ENEA Frascati” (RM)

DTT: Milestones and hold points

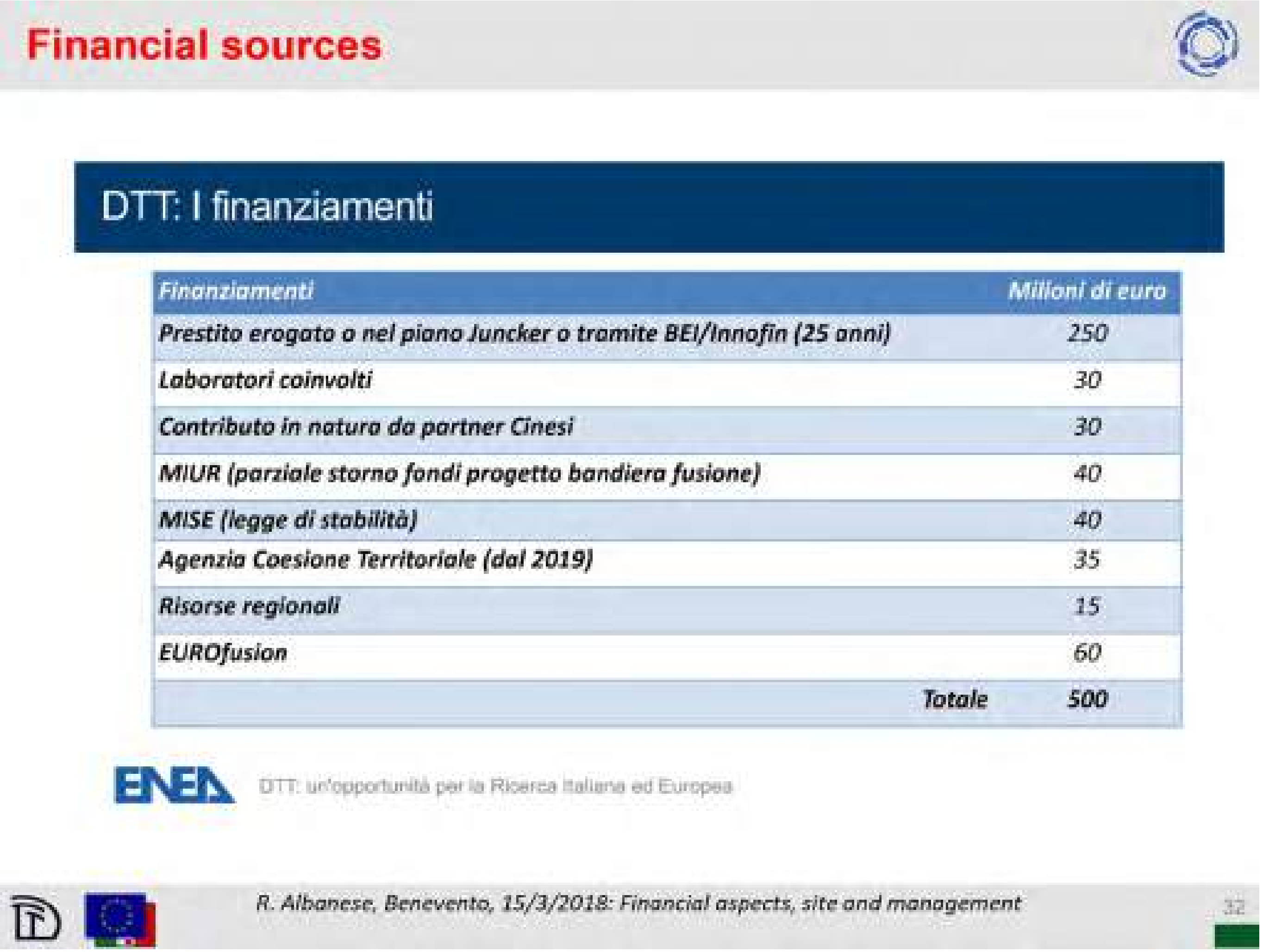
- Apr 2018: Frascati selected as DTT site
- July 2018: 1st Design Review Meeting of major components
- End 2018: Launched first call for tender procedure (for SC strands)
- End 2018: Recruitment of ENEA personnel started
- Mar 2019: 2nd Design Review Meeting
- Apr 2019 : DTT Interim Design Report

- **Mid-2019 : Establishment of DTT Consortium**
- **Mid-2019: Loan activated by EIB**

- 2022-2023: Decision on divertor configuration (PEX)
- 2022-2025: Assembly and commissioning
- End 2025: First experimental plasma: 3T, 2 MA
- 2025 – : Operations



DTT: i finanziamenti



Financial sources

DTT: I finanziamenti

Finanziamenti	*Milioni di euro*
Prestito erogato o nel piano Juncker o tramite BEI/Innofin (25 anni)	*250*
Laboratori coinvolti	*30*
Contributo in natura da partner Cinesi	*30*
MIUR (parziale storno fondi progetto bandiera fusione)	*40*
MISE (legge di stabilità)	*40*
Agenzia Coesione Territoriale (dal 2019)	*35*
Risorse regionali	*15*
EUROfusion	*60*
Totale	***500***

DTT: un'opportunità per la Ricerca Italiana ed Europea

R. Albanese, Benevento, 15/3/2018: Financial aspects, site and management

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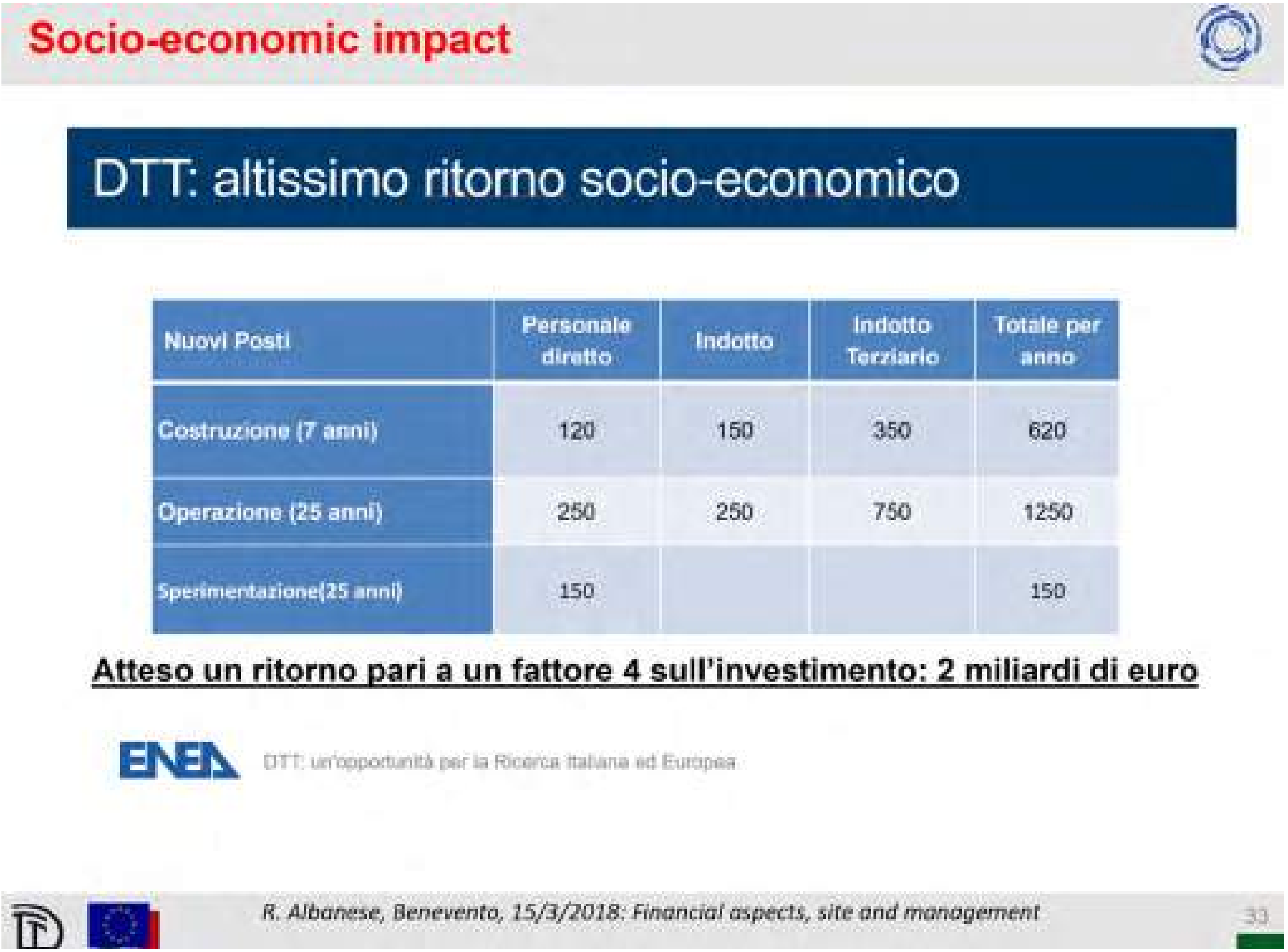
DTT: Ritorno socio-economico



Socio-economic impact

DTT: altissimo ritorno socio-economico

Nuovi Posti	Personale diretto	Indotto	Indotto Terziario	Totale per anno
Costruzione (7 anni)	120	150	350	620
Operazione (25 anni)	250	250	750	1250
Sperimentazione(25 anni)	150			150

Atteso un ritorno pari a un fattore 4 sull'investimento: 2 miliardi di euro

ENEA DTT: un'opportunità per la Ricerca Italiana ed Europea

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Member of EUROfusion

Consorzio CREATE: general information

- CREATE (Consorzio di Ricerca per l' Energia, l' Automazione e le Tecnologie dell'Elettromagnetismo) is a no-profit research organization, established as a legal entity (Consorzio) since 1992

- The core business is the scientific and technological research in electric, electronic, mechanical engineering and Automation.

- Presently, nuclear fusion and robotics are the main fields of activity

- Partners (with equal shares) of the Consortium are:
  - Ansaldo Energia SpA;
  - Università degli Studi della Basilicata
  - Università degli Studi della Campania "Luigi Vanvitelli"
  - Università degli Studi di Cassino e del Lazio Meridionale
  - Università degli Studi di Napoli "Federico II" (host partner)
  - Università degli Studi di Napoli "Parthenope"
  - Università degli Studi "Mediterranea" di Reggio Calabria

Consorzio CREATE: missions in fusion research

- Fusion relevant background studies
- Development of new modeling techniques
- Code development
- DTT design
- ITER design
- DEMO studies
- Experimental campaigns (e.g. JET, TCV in Europe, EAST in China)
- Education at PhD level
- Training of young post-doc researchers
- Diffusion of scientific culture

Consorzio CREATE: effort in fusion research (2016 data)

- **More than 60 collaborators (at professional level), of which:**
  - 30 permanent university staff (from partner universities)
  - 12 researchers under consultancy contract with CREATE
  - 7 researchers under employment contract
  - 9 PhD students (International Doctorate in fusion)
  - Other (e.g. voluntary or occasional collaborators)

- **More than 36 ppy spent in fusion activities, of which:**
  - About 14 ppy as manpower provided by the partner universities
  - About 11 ppy from employees and consultancy contracts with CREATE
  - About 9 ppy from PhD students
  - More than 2 ppy from other forms of collaboration

- **Main institutional and contractual involvements**
  - EUROfusion grant (linked third party of ENEA)
  - F4E grants (mainly ITER magnetic diagnostics)
  - F4E service contracts (mainly electromagnetic analysis)
  - ITER IO contracts (mainly plasma control system)

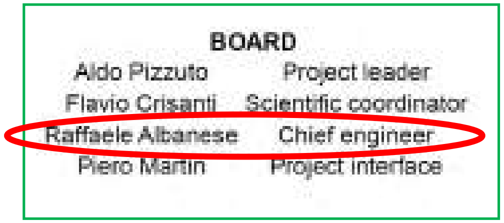
Consorzio CREATE: Involvement in EUROFusion and DTT

Involvement in EUROFusion as a Third Part of ENEA (2017 data)

- Contribution to most WPs
- Project Leadership: DTT2
- Project Board Chair: D&C
- Training: 5 Engineering Grants
- Education : contribution to the Int'l Doctorate in Fusion: 3 PhD per year (9 in total)
- Support to PMU: 2 secondees

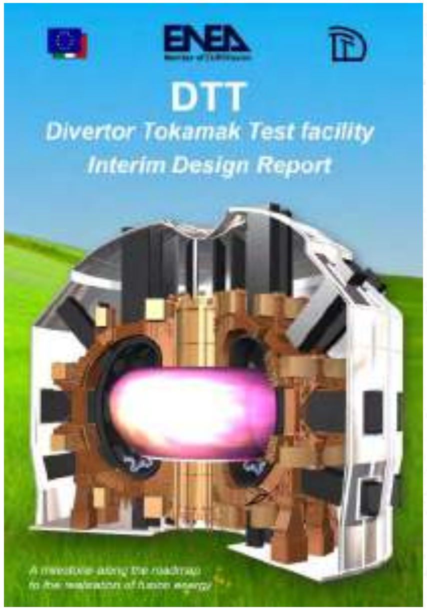
Involvement in the DTT Project (2019 data)

1 DTT Board member



BOARD	
Aldo Pizzuto	Project leader
Flavio Crisanti	Scientific coordinator
Raffaele Albanese	Chief engineer
Piero Martin	Project interface

23 DTT IDR contributors



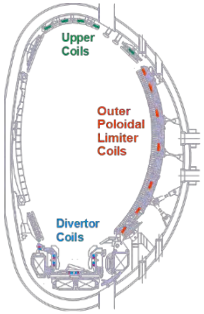
ENEA - CREATE
R. Albanese
R. Ambrosino
M. Ariola
A. Castaldo
D. Coccorese
V. Coccorese
M. de Magistris
G. De Tommasi
G. Di Gironimo
R. Fresa
S. Grazioso
F.P. Loschiavo
R. Martone
D. Marzullo
M. Mattei
A. Mele
R. Mozzillo
F.P. Orsitto
A. Pironti
G. Rubinacci
A. Tarallo
S. Ventre
F. Villone

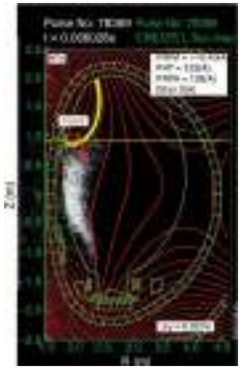
3 Task Coordinators

NAME	TASKS
Gian Mario Polli	**Management implementation**
Giuseppe Ramogida	Management implementation
Sandro Sandri	Radio-protection and licensing
Luigi Di Pace	Quality assurance
Raffaele Martone	Interim design report
Angelo Antonio Tuccillo	Physics tasks
Paolo Innocente	Power exhaust
Roberto Ambrosino	Plasma scenarios
Rosaria Villari	Neutronics
Aldo Di Zenobio	Magnet system
Giuseppe Di Gironimo	Mechanical components
Selanna Roccella	**Thermohydraulic design**
Paolo Rossi	In-vessel components
Gustavo Granucci	Heating and current drive
Alessandro Lampasi	Power supply system
Claudia Lanchi	Building
Antonio Cucchiaro	Layout
Giuseppe Mazzitelli	Auxiliary systems
Antonio Frattolillo	Cryogenic system
Alex Rydzy	Water cooling system
Marco Valisa	Diagnostics
Vincenzo Vitale	Instrumentation and control

Consorzio CREATE: Some achievements in experimental devices

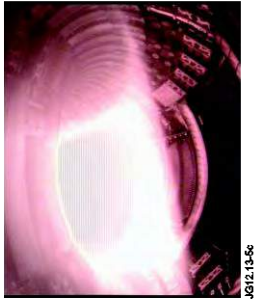
JET
Magnetic Diagnostics Enhancement





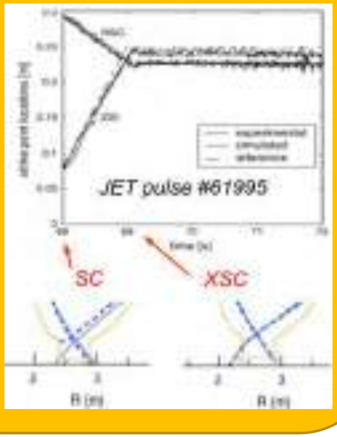
Pulse No: 80400 @ 0.04s:
Standard (radial bias =0)

Pulse No: 80402 @ 0.03s:
Radial bias = 240A,
optimum predicted

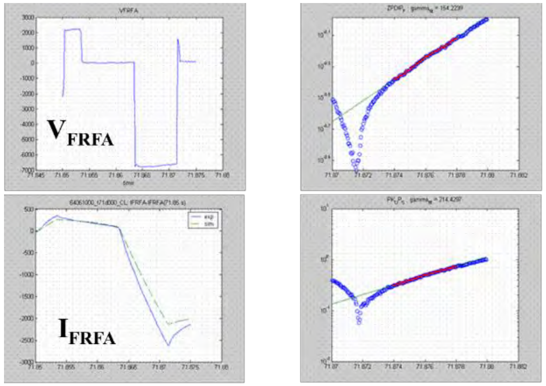


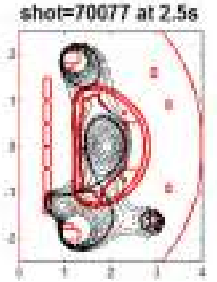
JET
Breakdown Optimization

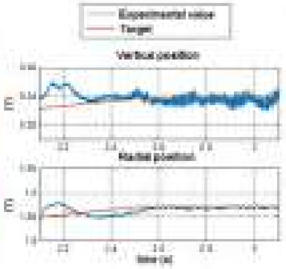
JET XSC
Extreme Shape Controller



JET PCU
Plasma Vertical Stabilization Control System







ITER-like voltage driven vertical stabilization system successfully tested at the EAST tokamak in Hefei, China: A keynote step toward MIMO control of advanced configurations

Member of EUROfusion

AIAN

Università degli Studi della Campania Luigi Vanvitelli

Il contributo industriale alla fusione nucleare

Involvement of Italian industries in the ITER Projects

Un successo industriale

ANGELANTONI TEST TECHNOLOGIES, ANSALDO NUCLEARE, ASG SUPERCONDUCTORS, CECOM, C.M.C. SUD, CNR, COELME COSTRUZIONI ELETTROMECCANICHE, CONSORZIO RFX, CONSORZIO SEA ALP ENGINEERING, C.R.E.A.T.E., CRIOTEC IMPIANTI, C.S.M., DELTA TI IMPIANTI, DE PRETTO INDUSTRIE, ENEA, ENERGY SUS, ENERGY TECHNOLOGY, ENGINSOFT, ERCOLE, ETTORE ZANON, FAGIOLI, ICAS, INFN, IRORES, LCG STUDIO LEGALE, L.T. CALCOLI, M&G, MANGIAROTTI, MICROELETTRICA SCIENTIFICA, NIDEC ASI, NIER INGEGNERIA, NISTICO, OCEM, POLITECNICO DI TORINO, RTM BREDA, SIMIC, S.I.S.T., SMM, S.R.S. ENGINEERING DESIGN, STAMPINOX, STUDIO INGEGNERIA MARCO FABBRI, UNIVERSITA' BICOCCA, UNIVERSITA' DI BOLOGNA, URS ITALIA, VENTRE, VITROCISET, WALTER TOSTO

Valore Totale oltre 900 milioni di euro
Oltre 500 PMI interessate

ENEA DTT: un'opportunità per la Ricerca Italiana ed Europea

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Opportunità di studio, ricerca e lavoro nella fusione nucleare

- Insegnamenti per CdL Mag.
  - ad es. Plasmi e Fusione Termonucleare Controllata ad UNINA

- Tesi e tirocini presso università e centri di ricerca italiani ed esteri
  - ad es. tirocini presso ENEA – Frascati

- Dottorati di ricerca
  - ad es. Int’l Doctorate in Fusion science and engineering, UNIPD

- Borse di studio
  - ad es. EEGs (Engineering Grants) presso EUROfusion

- Attività di ricerca
  - ad es. presso università, consorzi, EUROfusion, ENEA (concorsi nel 2019)

- Attività di tipo tecnico
  - ad es. presso centri di ricerca ed imprese