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

Lo sviluppo della tecnologia della fusione: il contributo dell'Italia

La deontologia nella comunicazione delle innovazioni su energia e salute

Auditorium Fondazione di Piacenza e Vigevano, 2 dicembre 2017

Mariano Tarantino
Fusion and Technology for Nuclear Safety and Security Department

ENEA is the Italian national Agency for applied research in the field of Energy and Sustainability

Overview on ENEA

ENEA is the Italian National Agency for New Technology, Energy and Sustainable Economic Development is in the field of:

Energy	Nuclear, Renewable, Efficiency, Technology
Sustainability	Environment, Health, Agro-Industrial
New Technologies	Materials, Security, Modelling, IT

Yearly Turnover: €285Mn

Staff: ~2,700 FTEs

11 Research Centers

ENEA Business Model

ENEA's business model:

- Develop innovative products and processes to commercial viability
- Provides services to private companies and public administration

Department of Fusion and Technology for Nuclear Safety and Security Activities

FUSION (Frascati, Brasimone)

- ✓ Physics
- ✓ Technology
- ✓ Engineering
- ✓ Safety

FISSION (Bologna, Brasimone, Casaccia)

- ✓ Gen.IV: Design & Technology
- ✓ Safety
- ✓ Waste Management

Security, Health, Environment (Frascati, Casaccia)

Laser & Neutron based Systems for:

- ✓ Security
- ✓ CBRN-E Risks
- ✓ Environment and Medical applications

Italian Institute for Ionizing Radiation Measurement (Casaccia)

STAKEHOLDERS

- EURATOM
- FUSION for ENERGY
- ITER
- NATIONAL & INTERNATIONAL PRIVATE AND PUBLIC INSTITUTIONS
- IAEA
- OECD-NEA
- NATO
- MINISTRIES
- INDUSTRIES

ENEA delivers innovation through integrated capabilities and cooperation with industry and academia

INTEGRATION BETWEEN STAKEHOLDERS

1  **Basic Research**

2  **Technology**

3  **Engineering**

- knowledge
- Know how
- integration

4  **Industry Liaison**

- Transfer of IP, licenses, etc.
- Facilitator between ind., univ. and research agencies
- Joint R&D programs

5  **Education & Training**

- PhDs, Masters, Theses
- Joint R&D with universities

INTEGRATION FROM CONCEPT TO EXECUTION THROUGH R&D AND PROTOTYPING

What is Fusion?

- Fusion is the process that produces energy in the core of the Sun and other stars.
- Temperature in the core of the sun is ~15 million °C, pressure is 300 billion atmosphere

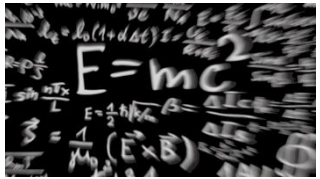
$$^{1}H + {}^{1}H \rightarrow {}^{2}H + e^{+} + \nu$$

$$^{1}H + {}^{2}H \rightarrow {}^{3}He + \gamma$$

$$^{3}He + {}^{3}He \rightarrow {}^{4}He + 2\,{}^{1}H + \gamma$$

The fusion of light hydrogen atoms (H-H) produces a heavier element, helium → Some mass has been lost and great mounts of energy have been gained

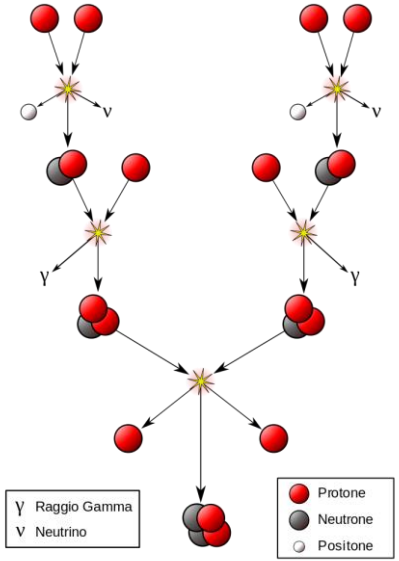
Every second 10^{38} p-p cycle takes place



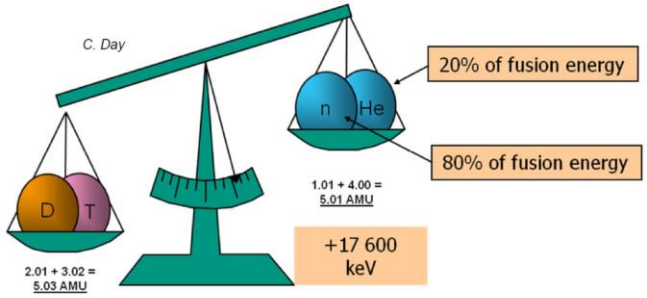
BUT……

A p-p reaction cycle in the core of the sun require more than 10^{10} (ten billion) years

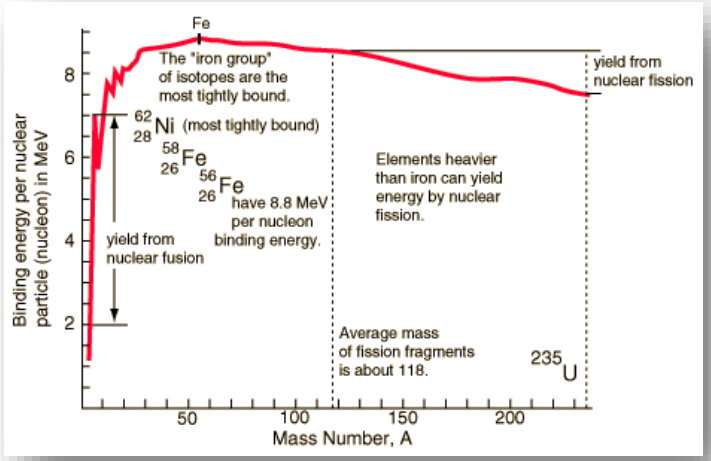
Power density in core is ~ 300 Wm^{-3} Would need 10^{7} m^{3} for a reasonable power station!

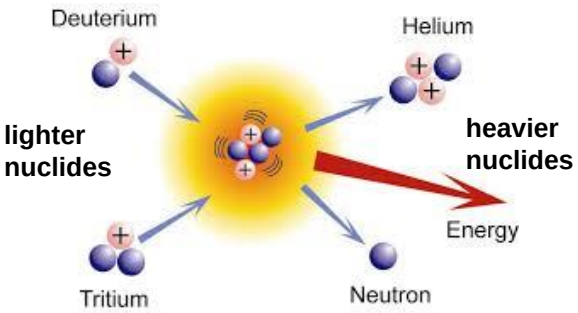


Which Fusion…



1 D-T reaction produces 17.6 MeV

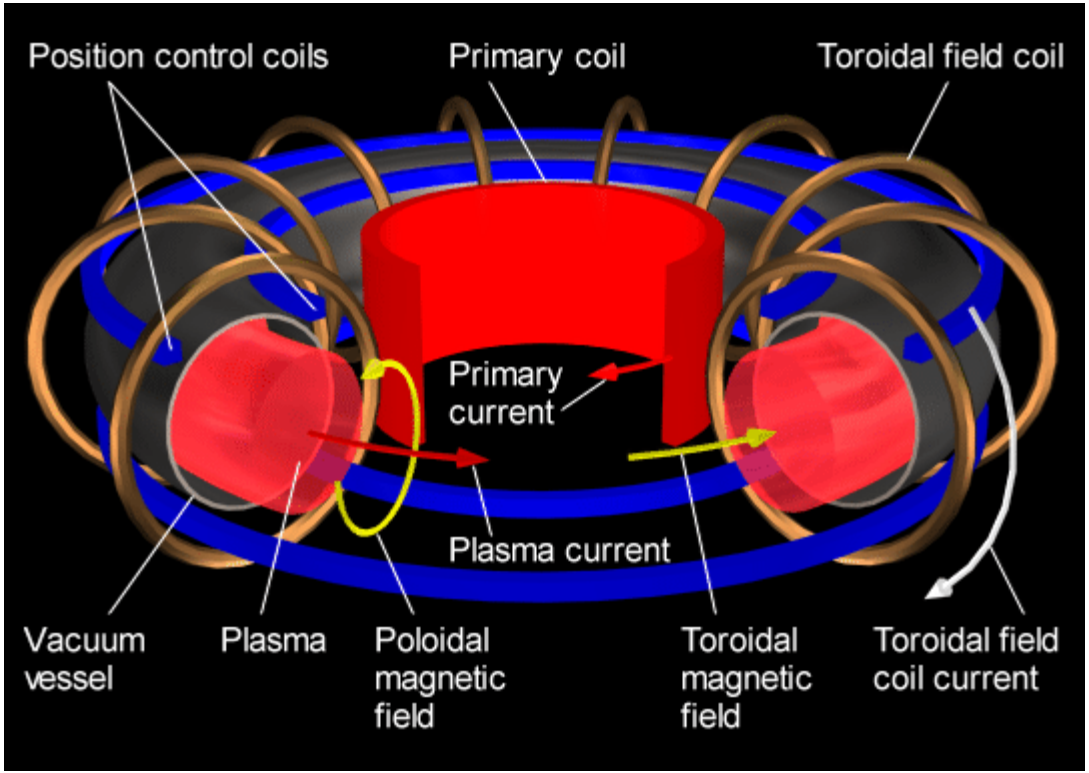




D-T reaction is initiated at the lowest temperature (5 keV~58 10^6 K) and presents the highest fusion cross-section @ 100 keV

$$^{2}_{1}D + ^{3}_{1}T \rightarrow ^{4}_{2}He(3.5\text{MeV}) + ^{1}_{0}n(14.1\text{MeV})$$

Fusion & Magnetic Confinement



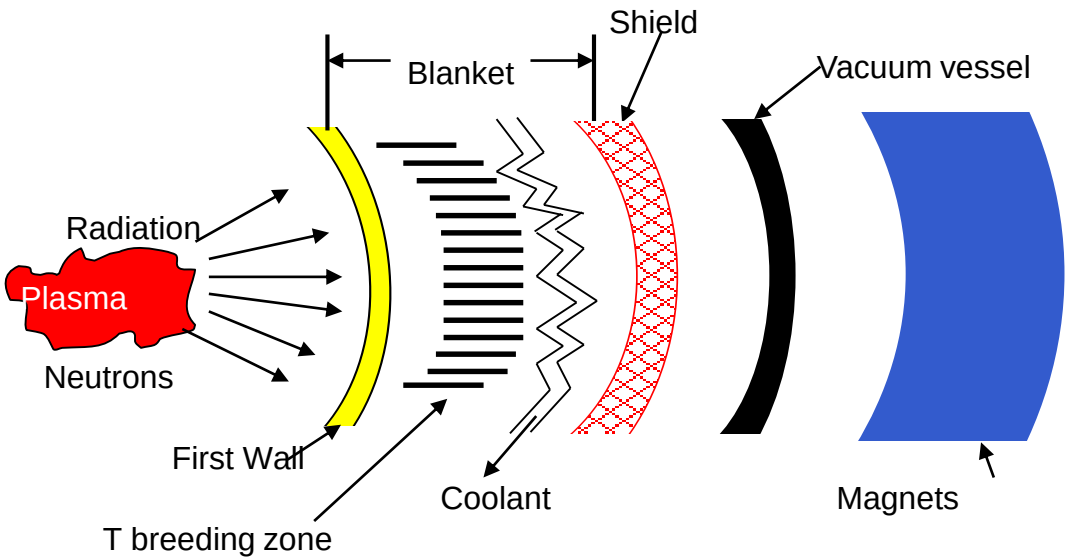
Typical Temperature 20 keV

(150 - 200 million K)

Magnetic Field

5-10 Tesla

Fusion Sustainability



FUEL

Deuterium can be extracted from natural water: SMOW (standard mean ocean water) contains 0.016% D

Tritium must be bred internally from lithium

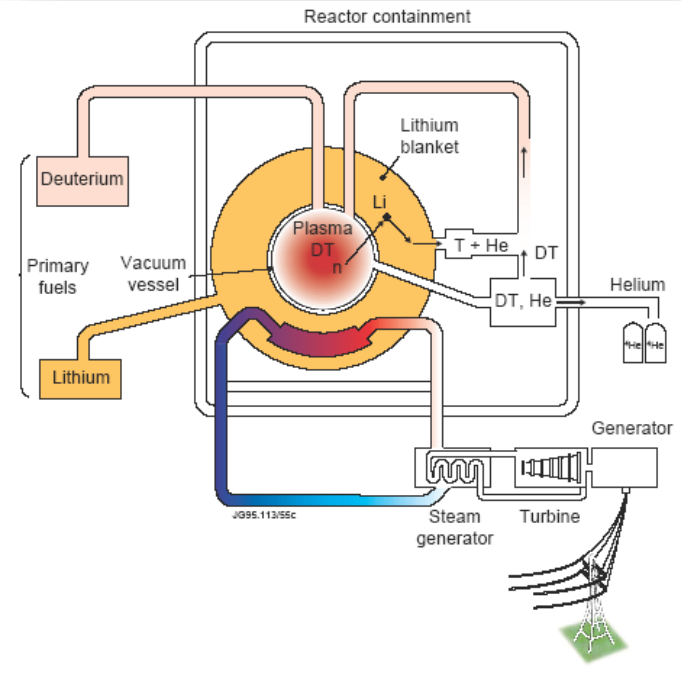
56 kg tritium is required per GW year of fusion power

Breeding reactions in a fusion reactor

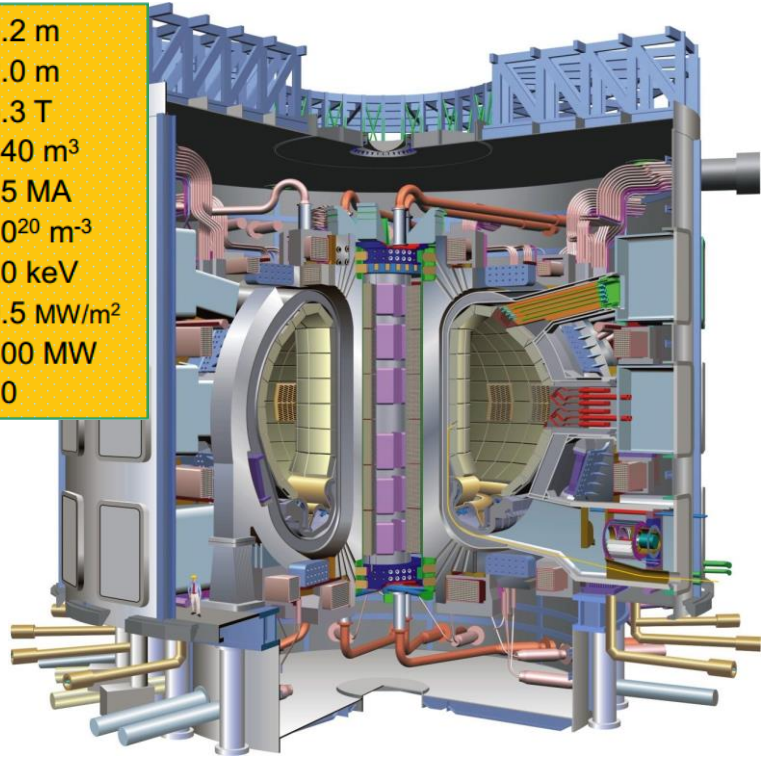
$$n + {}^{6}Li \rightarrow T + {}^{4}He$$

$$n + {}^{7}Li \rightarrow T + {}^{4}He + n$$

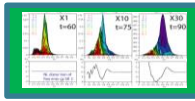
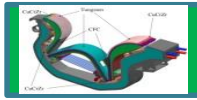
Fusion Machine….ITER



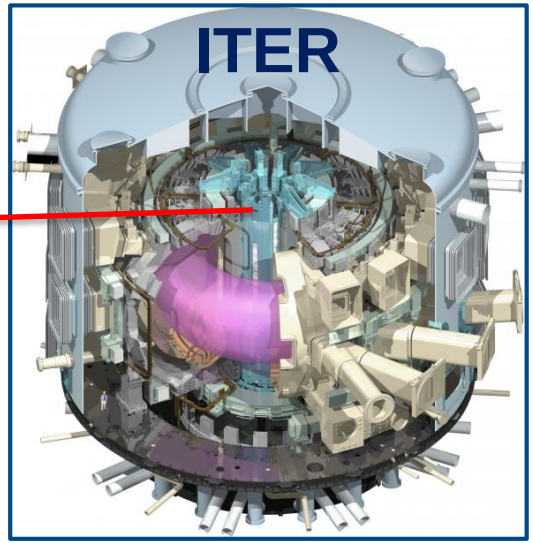
Major plasma radius	6.2 m
Minor plasma radius	2.0 m
Magnetic field	5.3 T
Plasma Volume	840 m^3
Plasma Current	15 MA
Typical Density	10^{20} m^{-3}
Typical Temperature	20 keV
Neutron flux	0.5 MW/m^2
Fusion Power	500 MW
Energy factor Q	10



ENEA Capabilities

 **Fusion Theory**	▪ **Among first to formalize a predictive plasma model** (“first principle code”, excellence recognized by US SciDAC)
 **Experimental Physics**	▪ **World Record of plasma density with Frascati Torus and Frascati Torus Upgrade** (two high magnetic field tokamaks)
 **High Heat Flux Technology**	▪ **World record of Critical heat flux** (35 MW/m^2, twice as much as rocket engine power at take off)
 **Remote Maintenance**	▪ New unique technology to perform **optical measurements in extreme environments** (i.e. high radiation, low accessibility)
 **Fusion Fuel Cycle**	▪ **Breakthrough in fuel cycle technology** allowing reduction in inventory of factor 3x-4x through improved tritium recovery and separation
 **Neutronics**	▪ **Worldwide reference Lab** on neutron database for: neutron shielding, tritium breeder and diagnostic design
 **Super-Conductivity**	▪ **World record:80 kA in a 43 mm dia cable** (sufficient for 8000 houses)

ITER Industrial Liaison Office

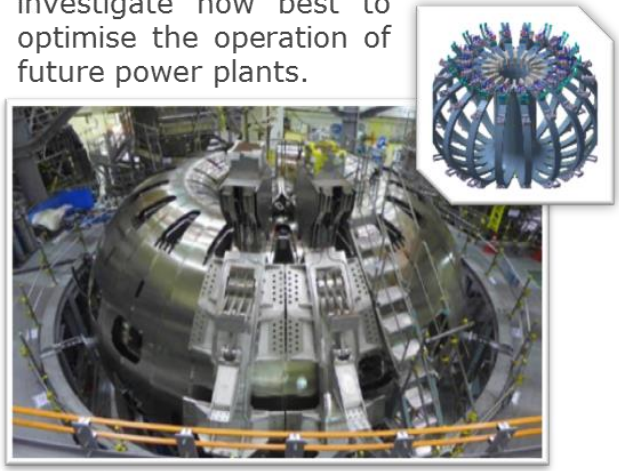


ENEA is playing the role of Industrial Liaison Officer towards F4E for ITER construction, facilitating industry participation

- More than 500 PMI involved
- Almost 1000 million euros the value of the high-tech contracts assigned to Italian Industries

Industrial Partnership

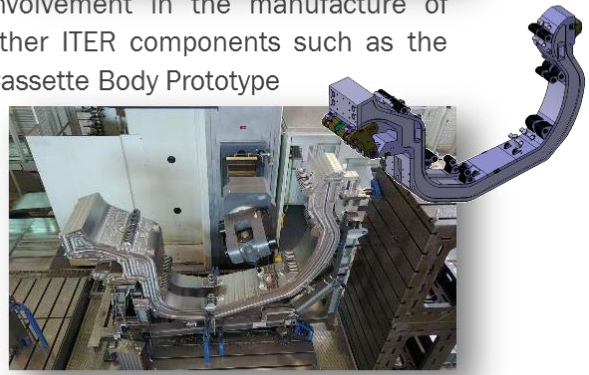
Supply of 18+2 Toroidal Field Coil Casings for JT-60SA, a fusion experimental project designed to investigate how best to optimise the operation of future power plants.



JT-60SA Toroidal Field Coil Casings

Supply of ITER Vacuum Vessel Sectors as a member of the AMW consortium

Involvement in the manufacture of other ITER components such as the Cassette Body Prototype



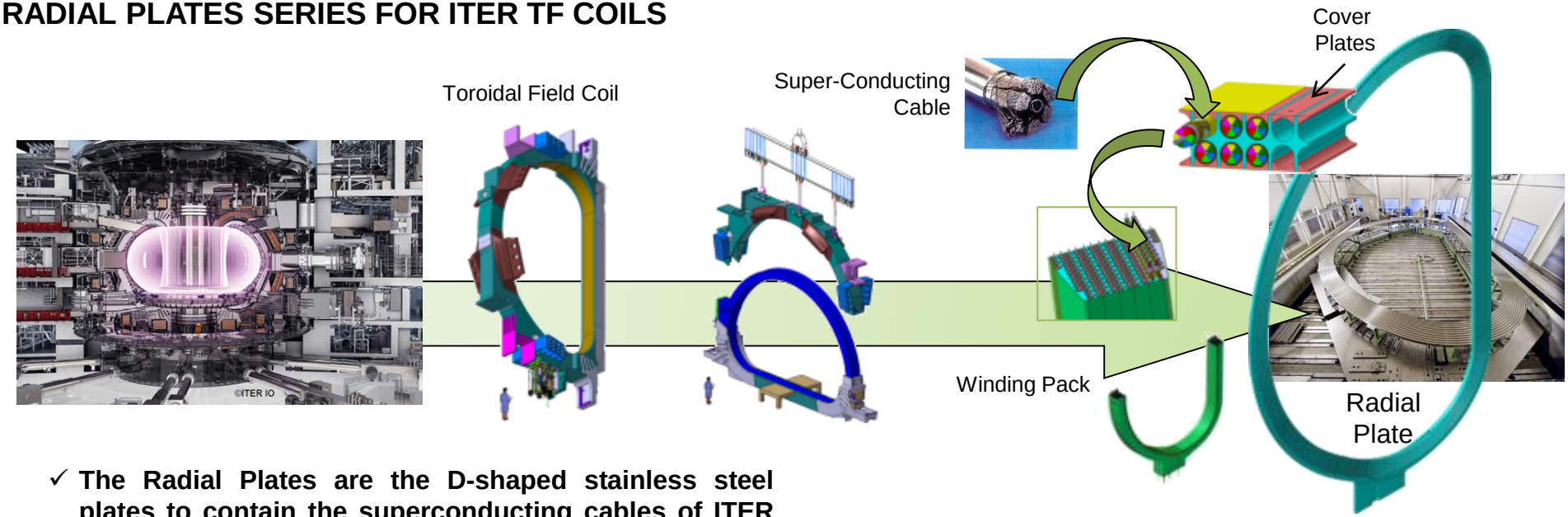
Manufacture of ITER Vacuum Vessel Sector components under the direction of Walter Tosto, member of the AMW consortium

Since its acquisition, the infrastructure has been completely renewed with energy efficient improvements, new machinery equipment, modern facilities for employees and today boasts state of the art facilities.

Industrial Partnership

SIMIC S.p.A.

RADIAL PLATES SERIES FOR ITER TF COILS



- ✓ **The Radial Plates are the D-shaped stainless steel plates to contain the superconducting cables of ITER TF coils**
- ✓ **Large size 13.8m x 8.7m x 110mm**
- ✓ **Very tight tolerances** (Planarity < 1 mm)

High technology welds in AISI 316 LN tested at -269°C

Industrial Partnership

Winding Packs COLD TEST & INSERTION INTO COIL CASES

SIMIC has been selected to perform the Cold Test of 10 TF Winding Packs and to supply the 10 **European Toroidal Field Coils** of ITER.
Contract with F4E was signed on May 2014 and it is expected to be completed by 2020.

Industrial Partnership

ITER Torodail Field Coils

The most sophisticated superconducting magnet in the world has been manufactured at the ASG Superconductors factory.

It has a height of 14 m, a width of 9 m and a weight of 110 tons equal to a large airplane.

This is the first of the 18 toroidal coils that will operate in ITER.

The coils will create a powerful magnetic cage in which the firing fuel will be captured, which should reach a temperature of 150,000,000° C.

When supplied with 68,000 A, the coils will generate a magnetic field that will reach **11.8 Tesla** - about 1 million times more powerful than the Earth's magnetic field!

It was shipped to ITER on November 20th, 2017.

Industrial Partnership

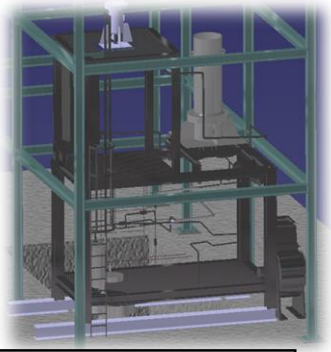
S.R.S. Servizi di Ricerche e Sviluppo S.r.l.

Fusion Technology Supporting Facility

Experimental plant for Tritium extraction (TRIEX)

LIFUS5 Mod3

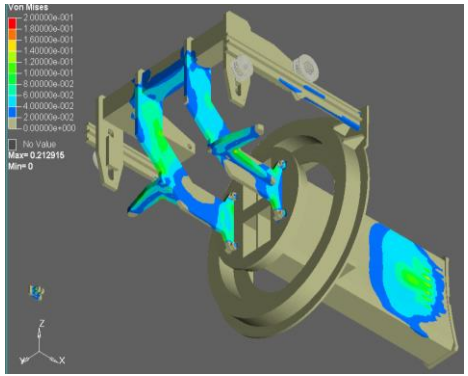
Test HAmmer in Lead LithIUM (THALLIUM)

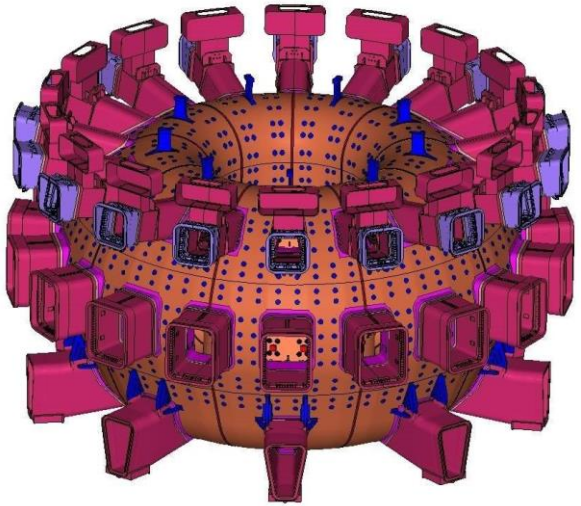


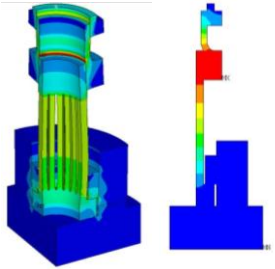
Integrated European Lead Lithium Loop (IELLLO)

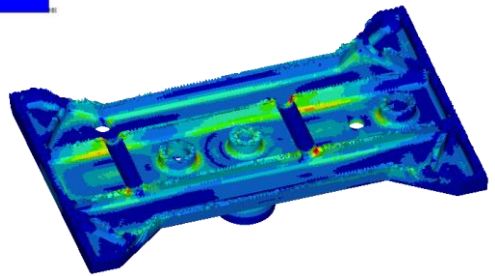
Industrial Partnership

S.R.S. Servizi di Ricerche e Sviluppo S.r.l.





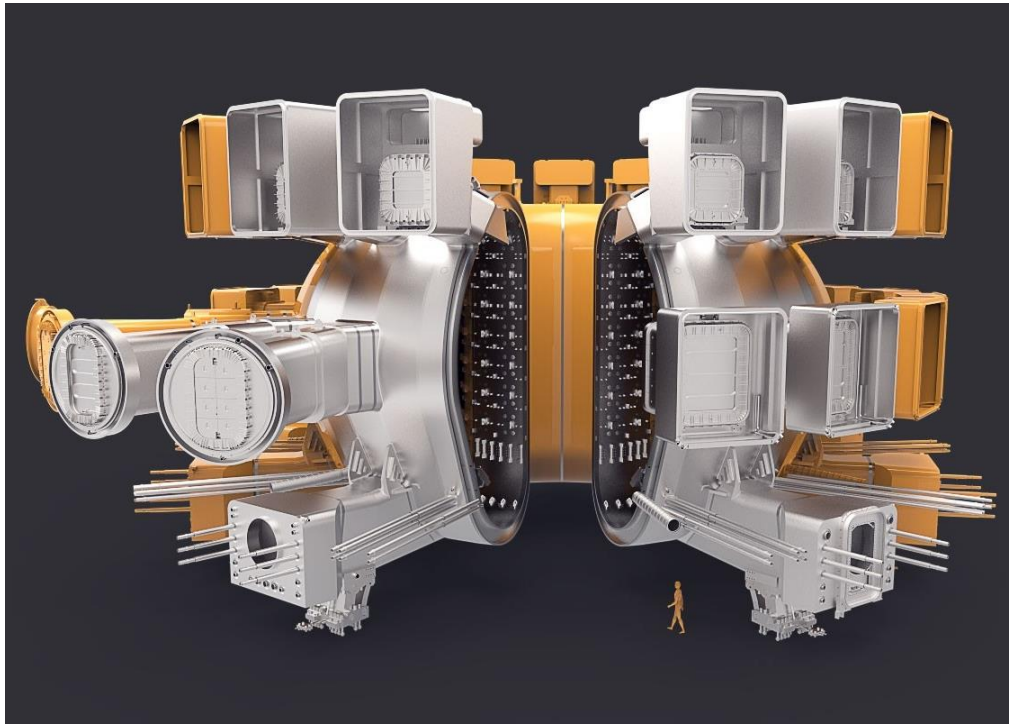




- Study, design and construction of robots for vacuum chamber tile repair/maintenance
- Conceptual design of ITER In Vessel Viewing System (IVVS) and Glow Discharge Cleaning (GDC)
- First Wall, Support Beam, and Vacuum Vessel Thermo-mechanical analysis (RCC-MR) for ITER

Industrial Partnership

ITER Vacuum Vessel



The Vacuum Vessel is hermetically-sealed steel container inside the cryostat that hoses the fusion reactor and acts as a first safety containment barrier. In its torus the plasma particles spiral around continuously without touching the walls.

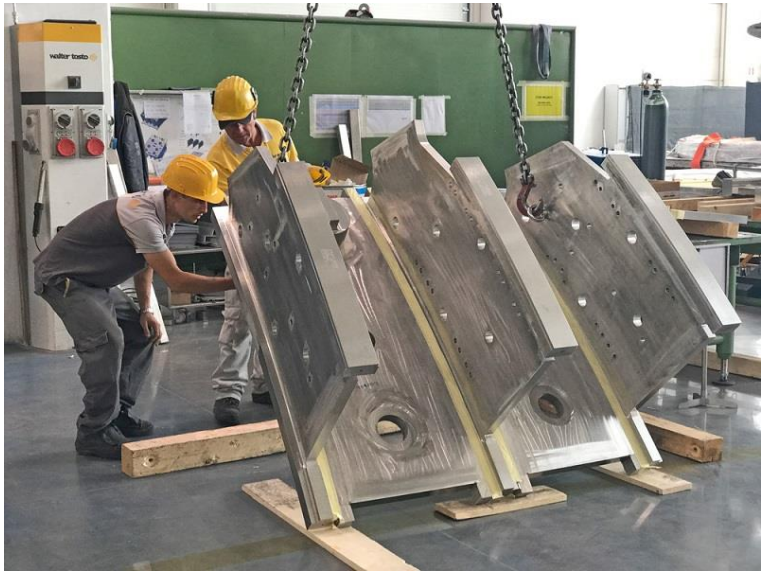
The ITER vacuum vessel, with an interior volume of **1,600 m³**, will provide an absolutely unique experimental arena for fusion physicists: the **volume of the plasma contained in the centre of the vessel (840 m³) is fully ten times larger than that of the largest operating tokamak in the world today**.

The ITER vacuum vessel will measure 19.4 m across (outer diameter), 11.4 m high, and weigh approximately 5,200 tonnes. (With the installation of the blanket and the divertor, the vacuum vessel will weigh 8,500 tonnes.).

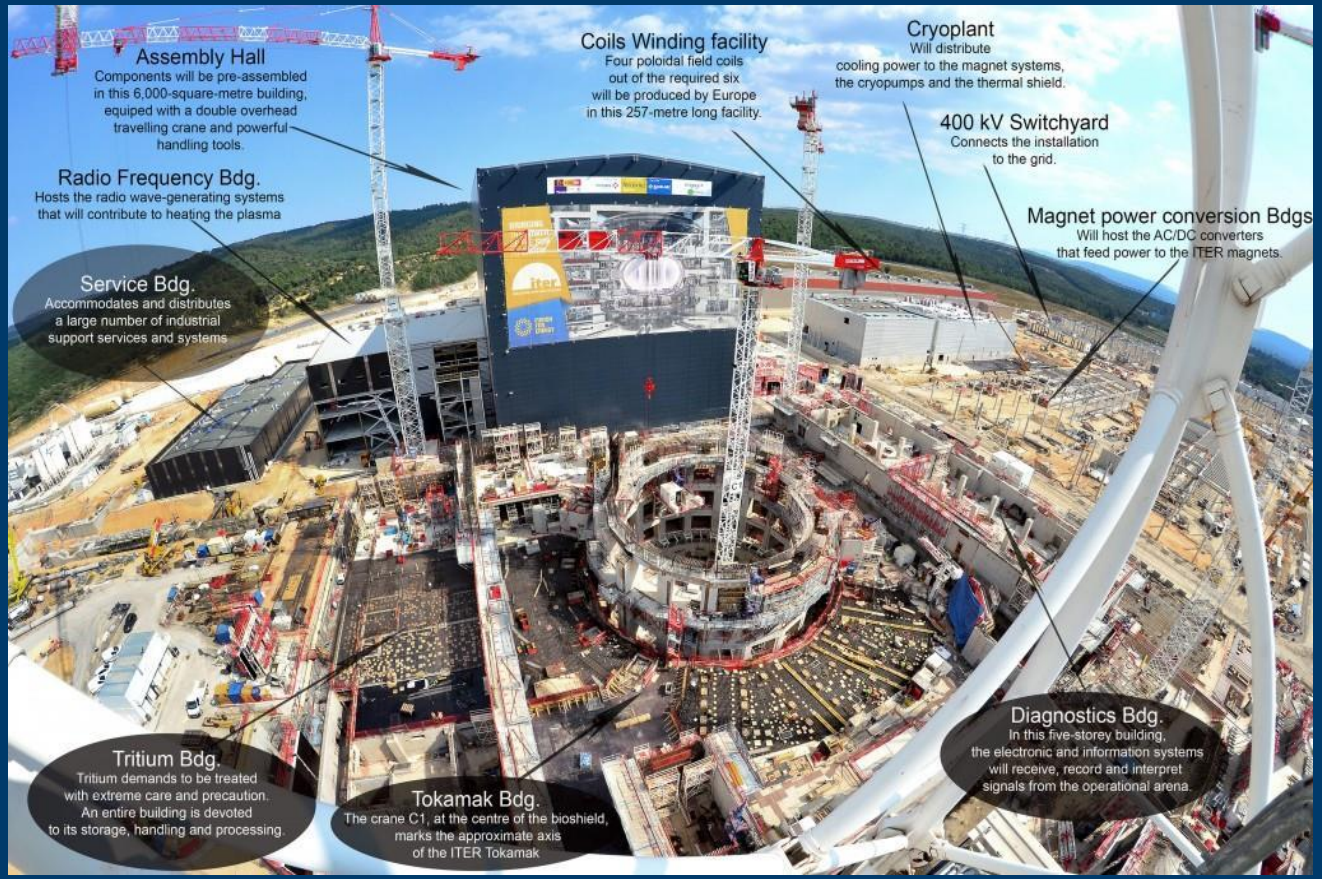
Industrial Partnership

ITER Vacuum Vessel

The AMW consortium (Ansaldo – Mangiarotti – Walter Tosto) is in charge of the manufacturing of seven sectors (7 out of 9) of the Vacuum Vessel for the ITER project .

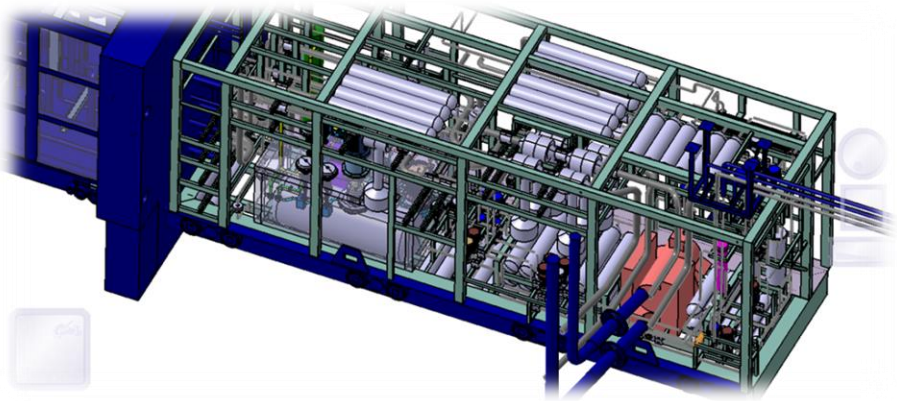


ITER Activities



Site infrastructure, July 3rd, 2017

Engineering Design of HCLL and HCPB TBMs



Port Cell #16 of ITER:
TRS, Pb-Li loop, HCS

Completion of the Conceptual Design and the Preliminary Design of

- Helium Cooling System (HCS)
- PbLi loop
- Coolant Purification System (CPS)
- Tritium Removal System (TRS) & Tritium Extraction System (TES)

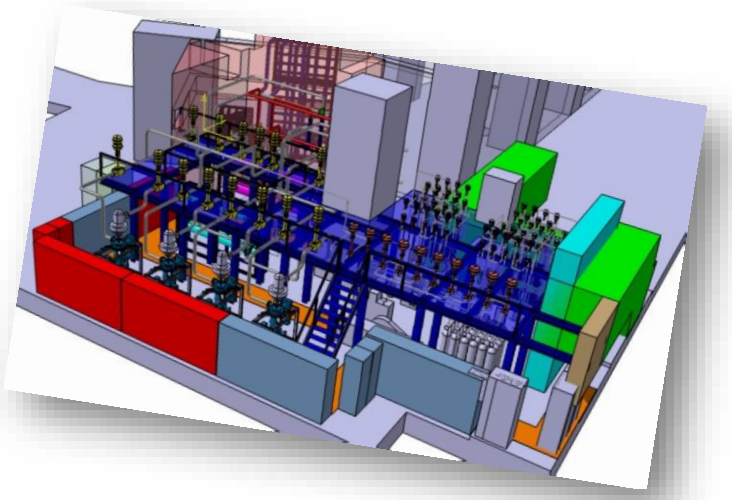
Consolidation of technical interfaces with ITER

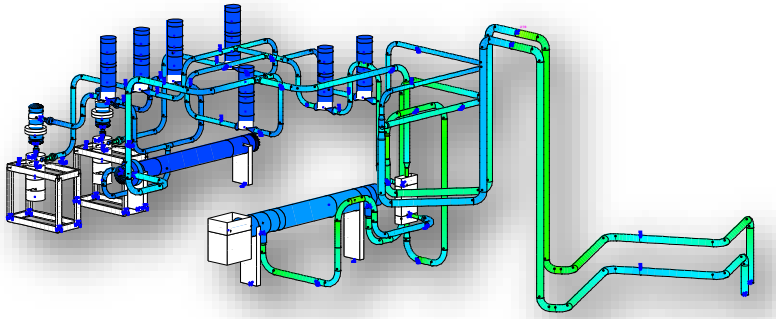
Radiation protection, releases during maintenance, accident analyses

Design of TBM Ancillary Systems

- This activity deals with the **design on European TBM ancillaries** (**Cooling and Tritium systems**) and their **integration in ITER**

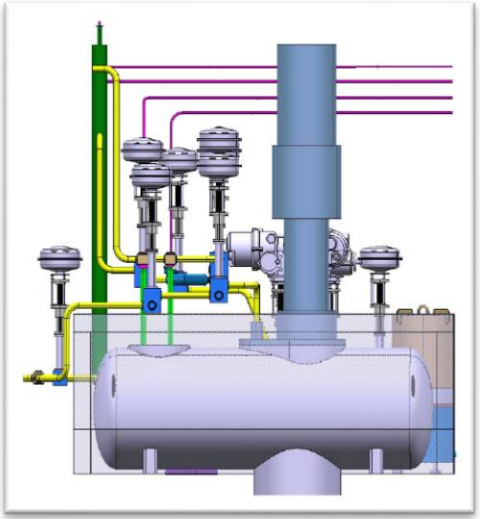
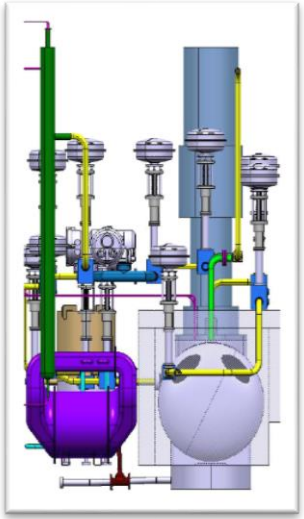
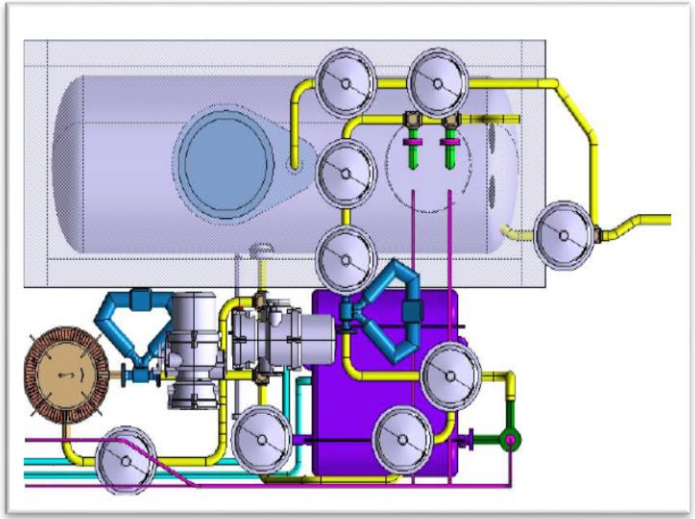
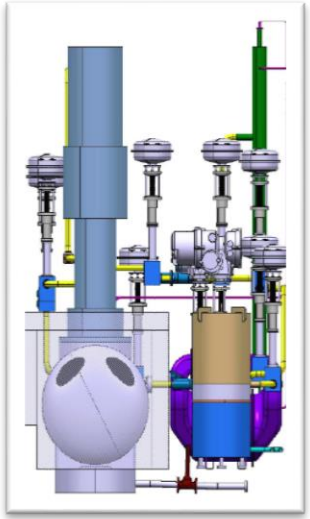
- **ENEA coordinates a consortium with KIT and other partners as subcontractors** (TPI, Wigner, CV-Rez, Palermo University, CREATE)





Helium Cooling System Layout in CVCS

Design of TBM Ancillary Systems

Lead Lithium Eutectic Loop Integration in ITER

Tritium Extraction System Qualification

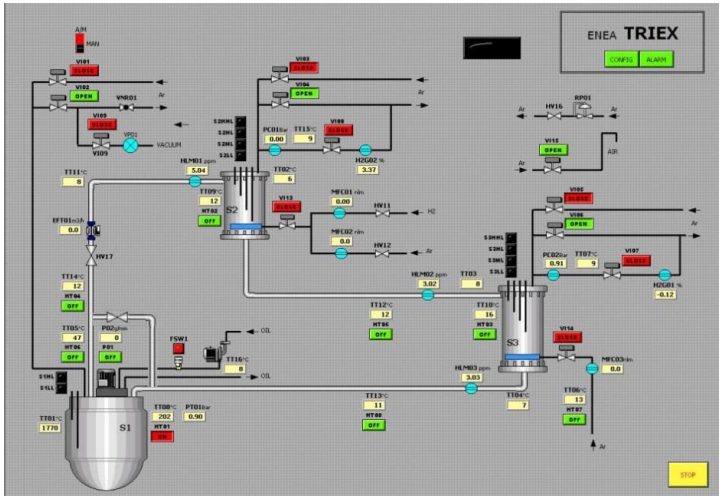
Investigation on TES for LLE blankets with different Technologies: GLC, PAV, VST

Gas Liquid Contactor Test Section

TRIEX Operative Conditions

- Processed fluid: Pb-16Li
- Design Pressure: 0.5 MPa (g)
- Design Temperature: 530 °C
- Max mass flow rate: 3.5 kg/s
- Stripping gas: Ar, Ar+H_2
- Pb-16Li inventory in the loop: 105 l
- Hydrogen partial pressure: 100-30000 Pa

TRIEX Layout



Coolant Purification System Qualification

HYDREX facility aiming at qualifying the Coolant Purification System of HCLL/HCPB TBM

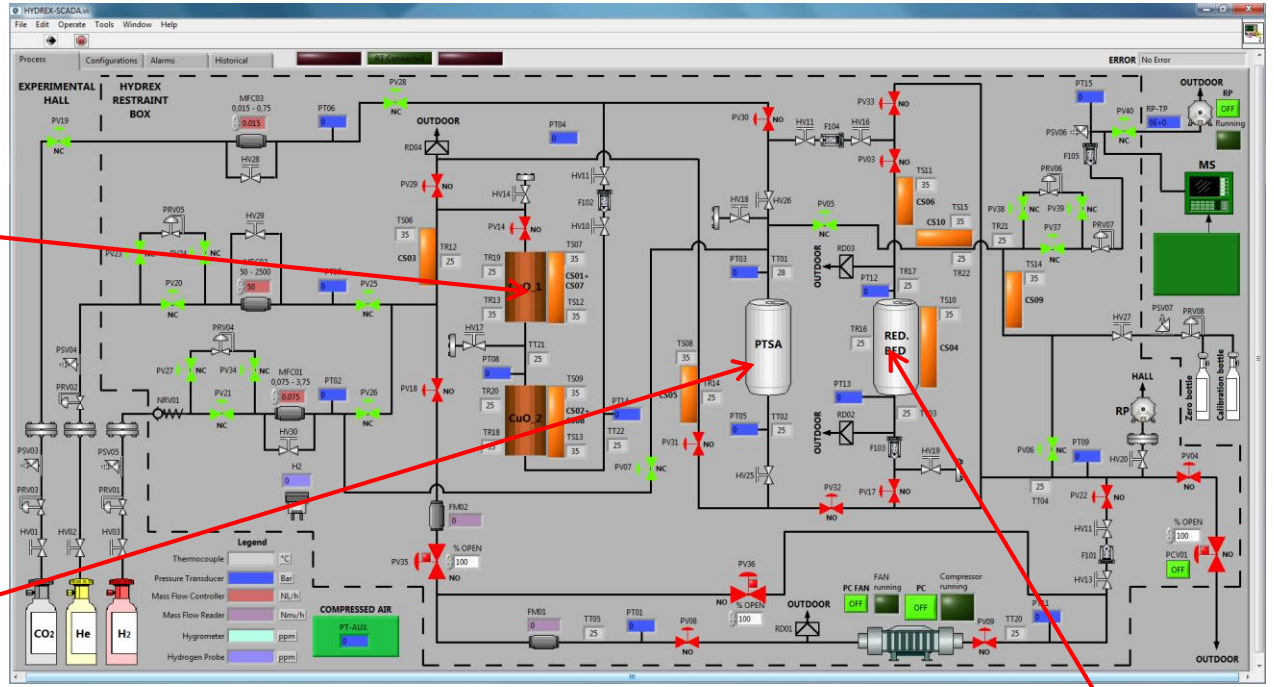
Q2 Oxidation : *BASF catalyst PURISTAR® R3-11G* is a robust copper catalyst for the removal of oxygen from gases and liquids.

$CuO + H_2 \rightarrow Cu + H_2O$

An outstanding attribute of this catalyst is the stability of its matrix, enabling excellent regenerability, and long-term operation at temperatures as high as 275 °C.

PTSA => Q2O Adsorption

SYLOBEAD® MS 564 C	molecular sieve Type 3°
SYLOBEAD® MS C 544	molecular sieve Type X
MOLSIV™ TE 143R	molecular sieve Type 4°
MOLSIV™ PSA O_2 HP	molecular sieve Type X

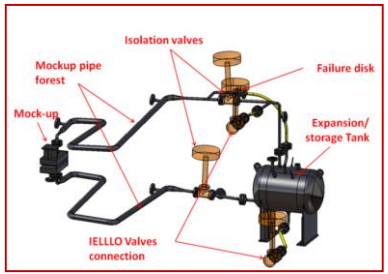


Reducing bed: SAES St909/Al

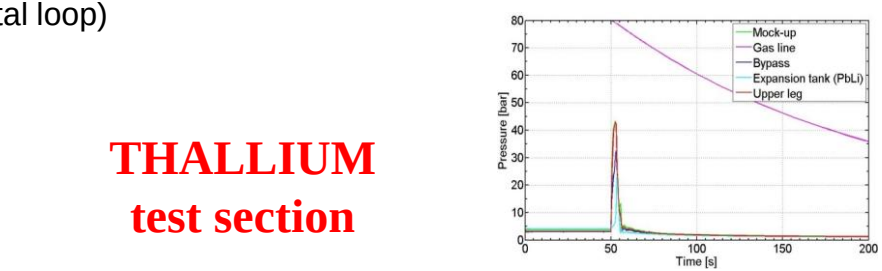
HCLL in-TBM LOCA

The object is to experimentally investigate, supported by numerical tool (RELAP5-3D), the pressurization of LLE loop due to **HCLL in-TBM LOCA** .

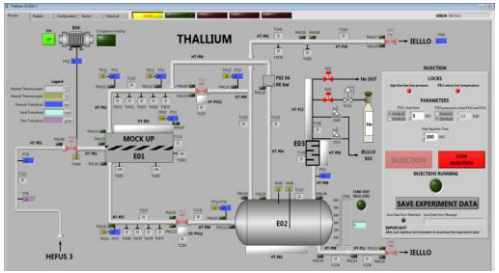
- Pressurization and the compression wave propagation into the LLE loop in case of injection of helium at 80 bar, 400°C due to the rupture of a cooling plates.
- Demonstrate capability of RELAP5-3D © to model single and two-phase (two fluid) wave propagation (fast transients in liquid metal loop)



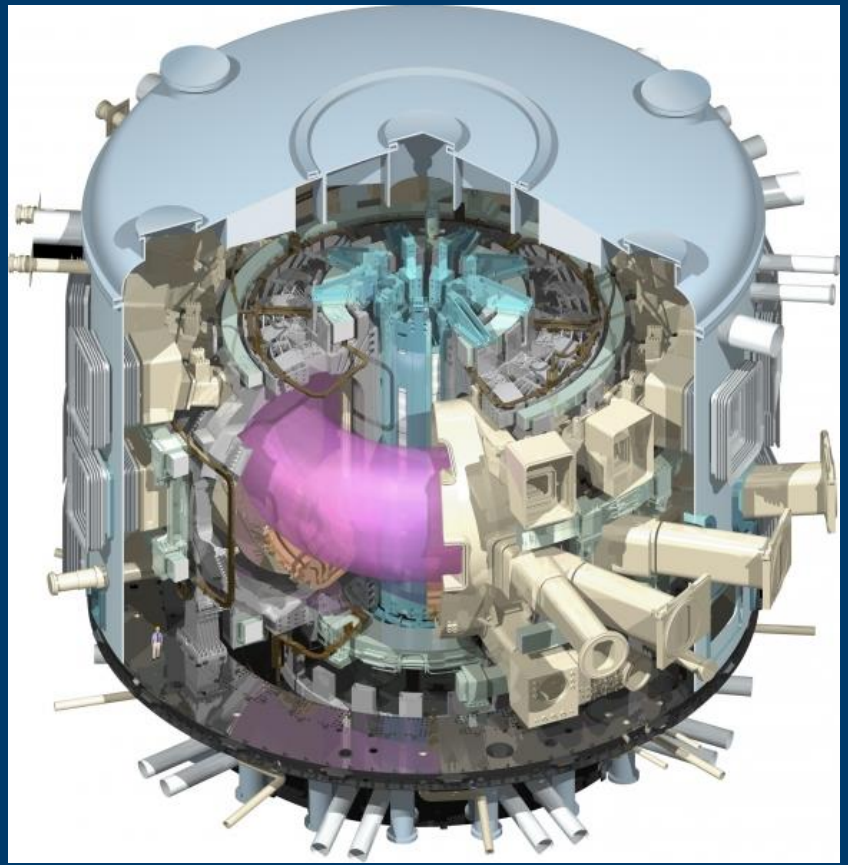
THALLIUM test section



Pressure trend in the first 150 s



THALLIUM DESIGN PARAMETERS	
PbLi volume	150 lt
PbLi temperature	400 °C
He injection pressure	80 bar
He injection mass flow	0,1-0,4 kg/s
Design pressure	80 bar



DEMO Activities

EUROfusion
POWER PLANT PHYSICS & TECHNOLOGY DEPARTMENT

Lithium Lead Eutectic Technology

ENEA is the coordinator of the LLE Technologies in EUROFUSION, which is organized as follow:

- **LLE Loop Design & Analyses (ENEA, CVR)**
- **MHD Analyses and code validation (KIT, CIEMAT)**
- **Corrosion (ENEA, KIT, CIEMAT, CVR)**
- **Coolant Chemistry & Purification (ENEA, CVR)**

ENEA is involved also in Tritium Technologies:

- **Consolidated model T transport in Breeding Unit for HCLL and WCLL**
- **Tritium Extraction from LLE (with H)**
  - **Permeation Against Vacuum (PAV)**
  - **Vacuum Siever Tray (VST)**

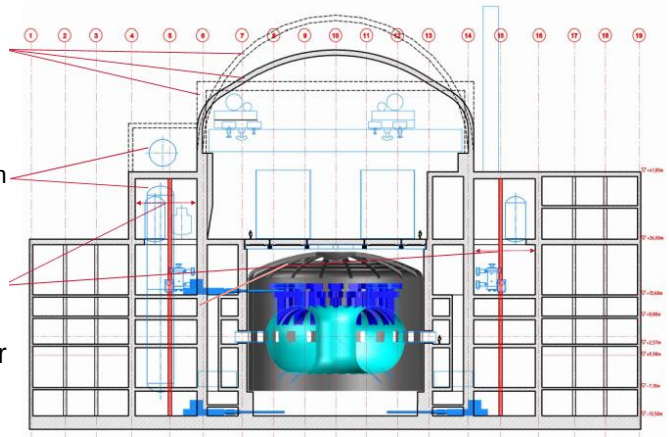
Lithium Lead Eutectic Technology

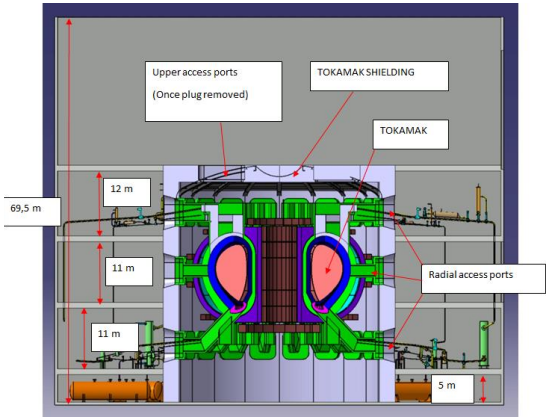
LLE loops integration in Tokamak building

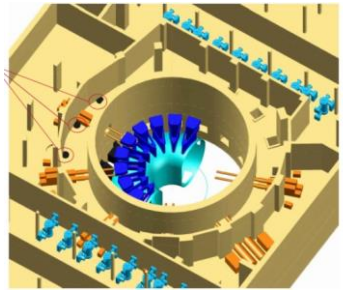
Cryogenic system/horizontal tank

Neutral beam

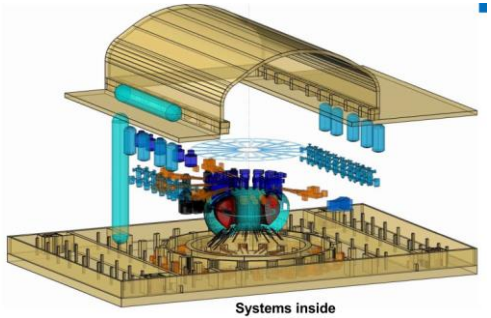
Heat transfer system





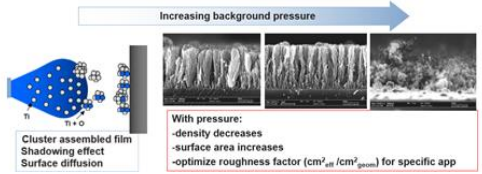


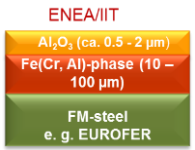
AREVA GmbH – Paul-Gossen-Straße 100 – 91052 Erlangen, Germany

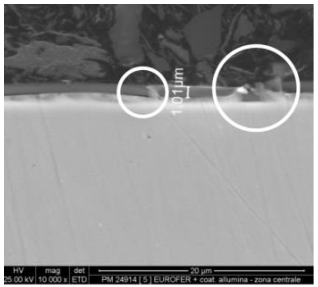


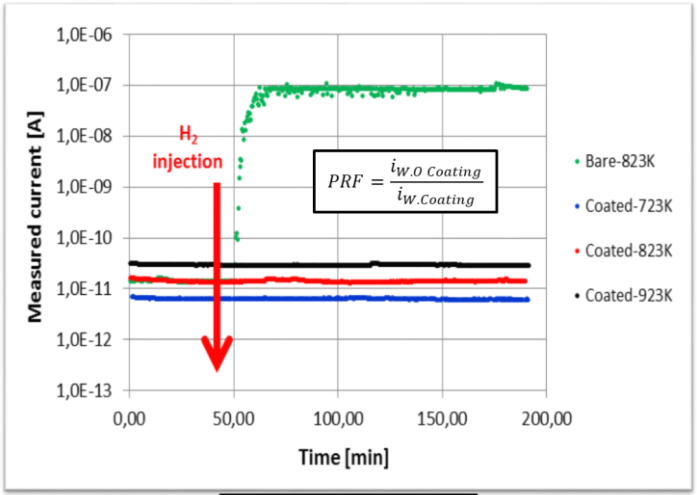
Lithium Lead Eutectic Technology

Antipermeation/corrosion PLD coating developed by IIT/ENEA









PRF in the range 1000-7000

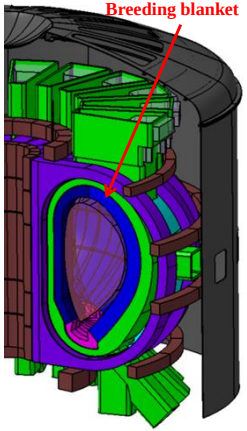
Permeation Tests performed on PLD coating:

Hydrogen permeation through PLD coated samples at 823 K and 923 K, Hydrogen partial pressure 100mbar.

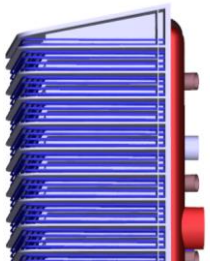
PERI II facility (ENEA)

WCLL Breeding Blanket Design

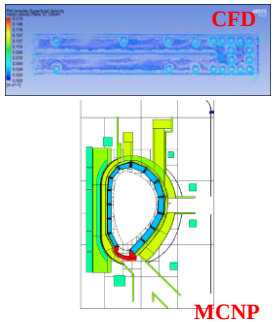
- **Objective** is to deliver feasible and integrated concept design of the WCLL BB for DEMO Plant at the Concept Design Review meeting
- WCLL BB has to withstand severe operating conditions, ensuring (1) **^{3}H self-sufficiency**, (2) **n-shielding** and (3) **coolant temperatures** for an efficient power conversion cycle
- WCLL BB features: (1) water as coolant; (2) Pb-15.7Li as breeder, n-mult and carrier; (3) Eurofer97 as structural material

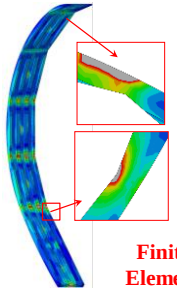


Establishing rationale and developing solutions of WCLL BB 2015 design → Analyses of the design solutions and feedbacks → Improvement of the design and exploiting alternative solutions → *Analyses of the NEW design solutions*

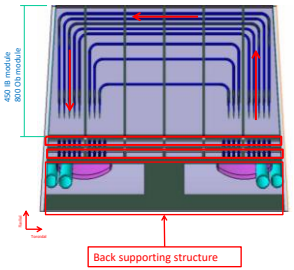


WCLL BB 2015





Finite Element TM



WCLL BB 2016

WCLL Safety Analysis: in-box LOCA

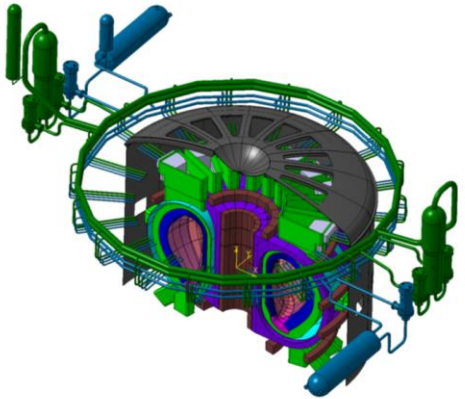
Objectives: to address the safety issues connected with PbLi/water interaction in WCLL BB in-box LOCA:

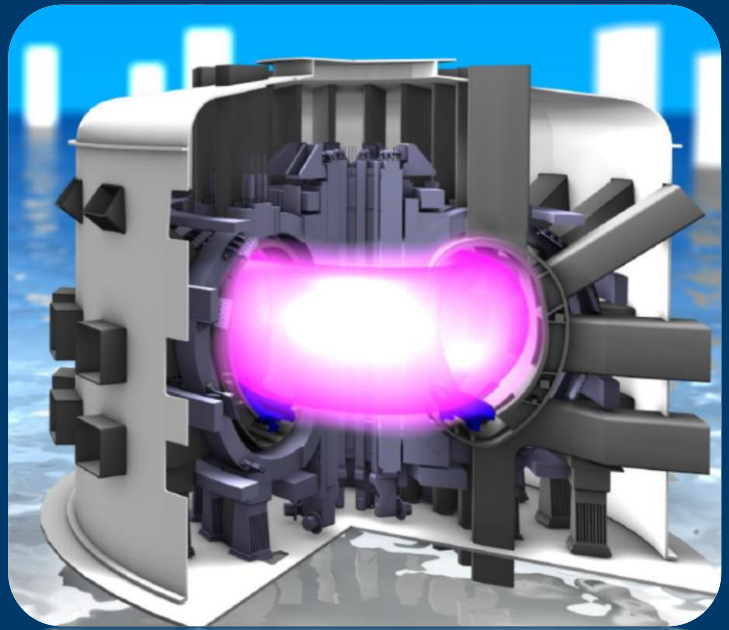
- developing a reliable numerical tool for deterministic safety analysis of WCLL BB in-box LOCA (**SIMMER code for fusion application**)
- applying a standard **code validation methodology** to SIMMER code
- designing and implementing a new **experimental campaign in LIFUS5/Mod3** addressed to code validation

WCLL Balance Of Plant

- **Objectives**
  - to perform power conversion studies for a Water Primary Heat Transfer System and a Power Conversion System. The reference configuration includes the integration of an Energy Storage System (working with HITEC) to cope with the pulse operation of DEMO
  - to perform R&D studies (experimental and numerical) about PbLi/water steam generators

- **Numerical tools**. RELAP5/Mod3.3 version modified with water, HITEC and PbLi fluid proprieties
- **Experimental infrastructure**. CIRCE facility @ CR Brasimone





Divertor Tokamak Test Facility

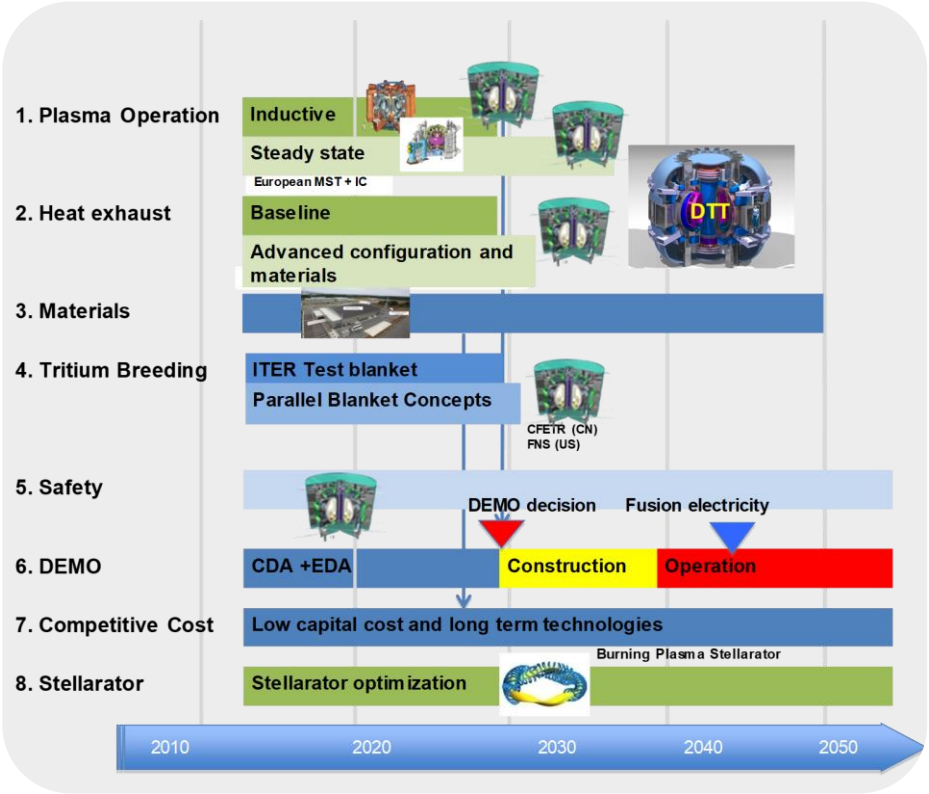
DTT Goal

- One of the main challenges in the European fusion roadmap is to **design a heat and power exhaust system able to withstand the large loads expected in the divertor of a DEMO fusion power plant**.

- In parallel with the programme to optimise the operation with a conventional divertor based on detached conditions to be tested on the ITER device, a specific project has been launched to investigate **alternative power exhaust solutions for DEMO, aimed at the definition and the design of a Divertor Tokamak Test facility**.

- **DTT should retain the possibility to test different divertor magnetic configurations, liquid metal divertor targets, and other possible solutions for the power exhaust problem**. The DTT design proposal refers to a set of parameters selected so as to have edge conditions as close as possible to DEMO, while remaining compatible with DEMO bulk plasma performance in terms of dimensionless parameters within a set of constraints related to flexibility and costs.

European Roadmap



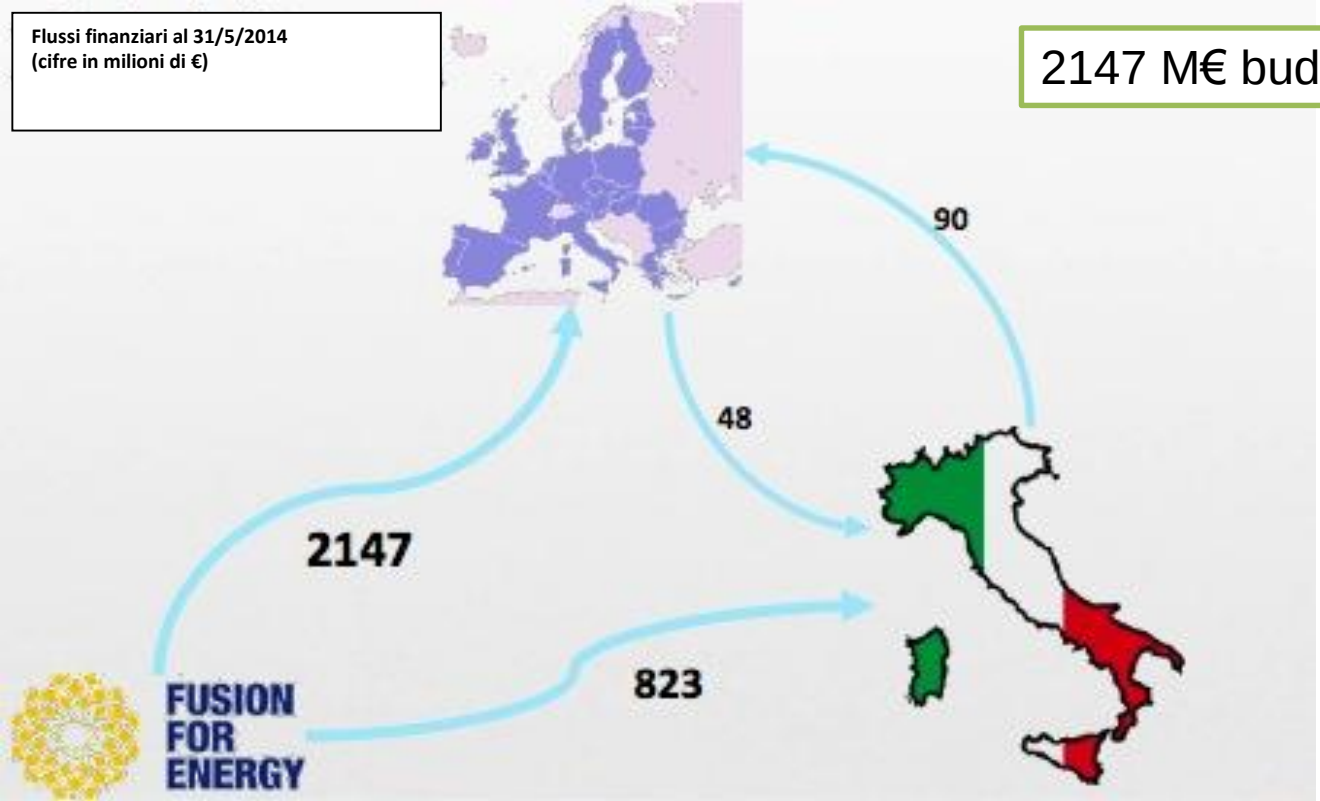
DTT Facility aiming at supporting DEMO development.

Complementary to ITER

DTT Partnership

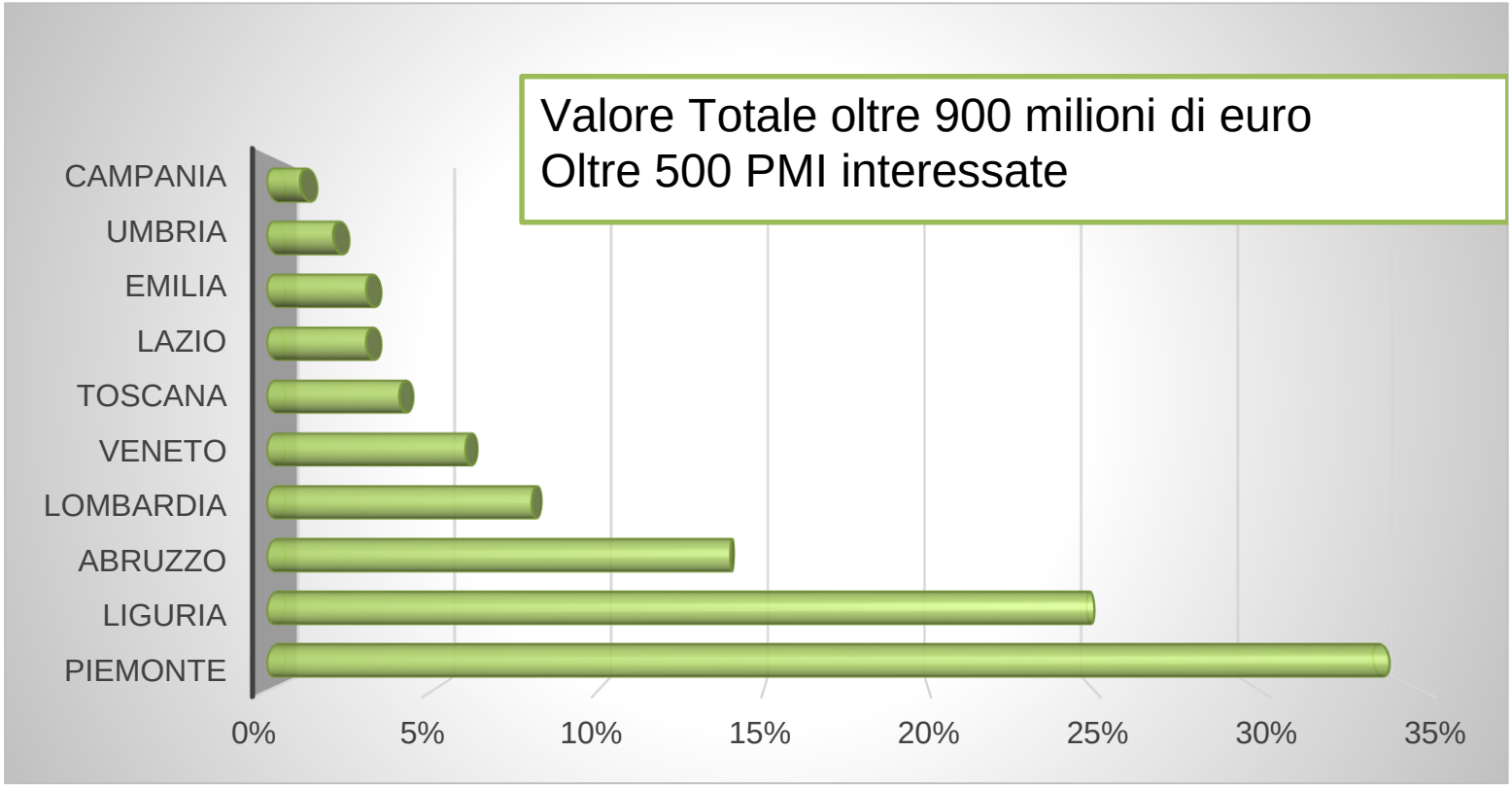
Beneficiario ENEA	**Agenzia nazionale per le nuove tecnologie, l'energia e lo sviluppo economico sostenibile**		Università di Catania
CONSORZIO RFX	Consorzio RFX (Pd)		Università di Milano- Bicocca
IFP	CNR – Istituto Fisica del Plasma (Mi)		Università di Padova
CREATE	Consorzio CREATE (Na)		Università di Palermo
	Università Roma II - Tor Vergata (RM)		Università di Pisa
	Politecnico di Torino	AnsaldoNucleare	Ansaldo Nucleare (Ge)
POLITECNICO DI MILANO	Politecnico di Milano	CSM Centro Sviluppo Materiali	Centro Sviluppo Materiali (RM)
ROMA TRE UNIVERSITÀ DEGLI STUDI	Università Roma III	LT CALCOLI	LT Calcoli – (Mi)
INFN	Laboratori di Legnaro	CINECA	Centro Super Computer Bologna (CINECA)
	Università di Bologna		S.R.S. GROUP S.R.L. (RM)
iit	IIT Istituto Italiano di Tecnologia		

Italian Industries Competitiveness



2147 M€ budget include building

Distribution of contracts 2008-2015 in Italian regions



Budget

Funding	M€
Prestito erogato o nel piano Junker o tramite BEI/Innofin (25 anni)	250
Laboratori coinvolti	30
Contributo in natura da partner Cinesi	30
MIUR	40
MISE	40
Agenzia Coesione Territoriale (dal 2019)	35
Risorse regionali	15
EUROfusion	60
Totale	**500**

Socio-Economic feedback

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

Expecting a return of a factor 4 on the investment: 2 billion euros.

Status of the Project

- Italian Government committed in supporting the Project
- Project approved and funded by EUROFUSION
- Funds available
- Call for site online (deadline 31st January 2018)

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