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

RICERCA & TECNOLOGIE EMERGENTI

Mariano TARANTINO, Responsabile Divisione Sistemi Nucleari per l'Energia

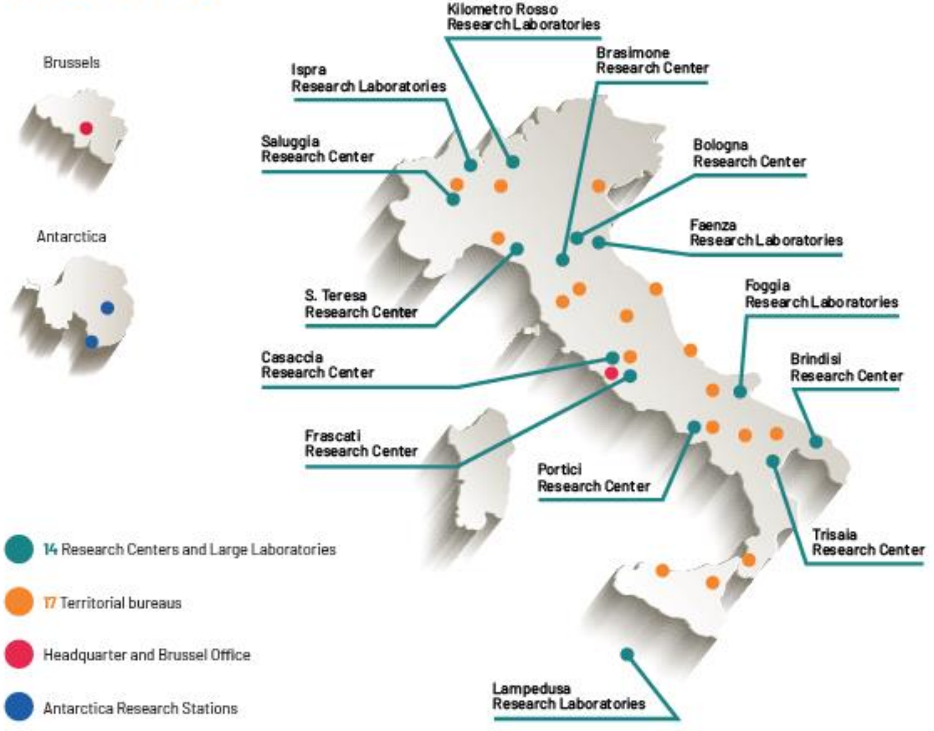
ENEA Italian National Agency for New Technologies, Energy and Sustainable Economic Development

Our strategic sectors

- RENEWABLES
- NUCLEAR
- SUSTAINABILITY
- ENERGY EFFICIENCY
- TECHNOLOGY TRANSFER

Research in all **energy sectors** (renewables, storage, sustainable mobility, hydrogen, smart cities, energy communities), including nuclear power.

Where we are



ENEA - *Organization Restructuring in 2024*

4 Departments:

- RENEWABLES
- NUCLEAR
- SUSTAINABILITY
- ENERGY EFFICIENCY

former “Fusion and Technology for Nuclear Safety and Security” → **NUCLEAR (NUC) Department:**

500 People

6 Technical divisions

19 Research laboratories

6 Technical Divisions:

- Plasma Physics
- Fusion Energy Development
- Experimental Engineering
- Radiation Systems and Applications
- **Nuclear Energy Systems**
- Physical Technologies and Safety

former "Nuclear Safety and Security» → **Nuclear Energy Systems**

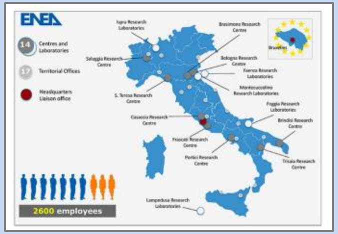
Italy-ENEA: R&D in Nuclear Technologies

Italy

- Italy plays a leading role in nuclear research and development
- Italy is acknowledged as a reference in:
  - **core design**, **passive safety systems**, **component prototyping** and **technological demonstration**.
- Several spin-offs of this leadership: contracts, collaborations and consultancies from all around the world.

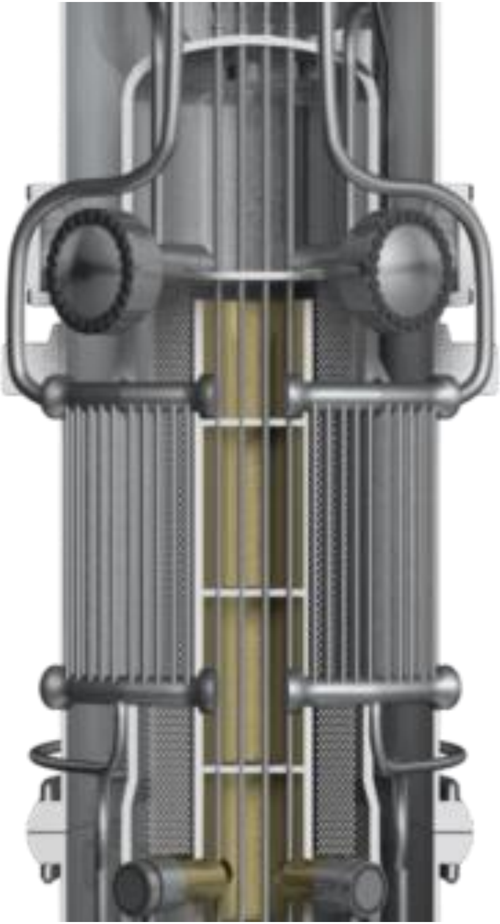
ENEA
Italian National Agency for New Technologies, Energy and Sustainable Economic Development

Since its very foundation, ENEA performs R&D on nuclear fission and plays an important role in Italy.



SMR

SMRs appear justified by the expectation that the **modularity of the plant systems allows prefabrication in production chains external to the site, to the advantage of a shorter duration and complexity of the work on site, with presumable better quality and lower costs.**



SMR

Limit capital intensity	Serial production	Modularization	Simplification & security	Smaller footprint	Flexible applications	Hybrid systems
• Lower upfront capital costs • Limited financing costs	• Learning curve effects • Leverage centralized factory production to limit costs and onsite activities	• Multi-module deployment with revenues from first module(s) financing next ones • Modular construction	• Reduced complexity enhancing overall safety, while limiting systems and components costs	• Reduced site size • Reduced emergency planning zone	• Remote locations • Marine based (floating, subsea) • Replacement of fossil-fired plants: retrofit ageing coal plant	• Enhanced load-follow performances • Non-power applications, e.g. H2, process heat

Improved competitiveness (Limit capital intensity, Serial production, Modularization, Simplification & security)

Extended market (Smaller footprint, Flexible applications, Hybrid systems)

Better affordability | **Reduced risks of cost overrun** | **Shorter construction time** | **Enhanced safety** | **Greater site flexibility** | **Wider range of users** | **Integration With RES**

Source: "Advances in Small Modular Reactor Technology Developments» IAEA Advanced Reactors Information System (ARIS) 2020 Edition

ENEA activities on SMRs Technology

In-depth studies for the **characterization of the passive systems modeling from the experimental and computational point of view** including **reliability assessment**.

- Thermal-hydraulic codes validation (TRACE, RELAP, CATHARE)
- Scaling analyses to characterize the code scaling-up capabilities
- Severe Accident Simulations

Participation in **European projects**

PASTELS: works on improving numerical tools to accurately simulate some of the most promising safety passive systems.

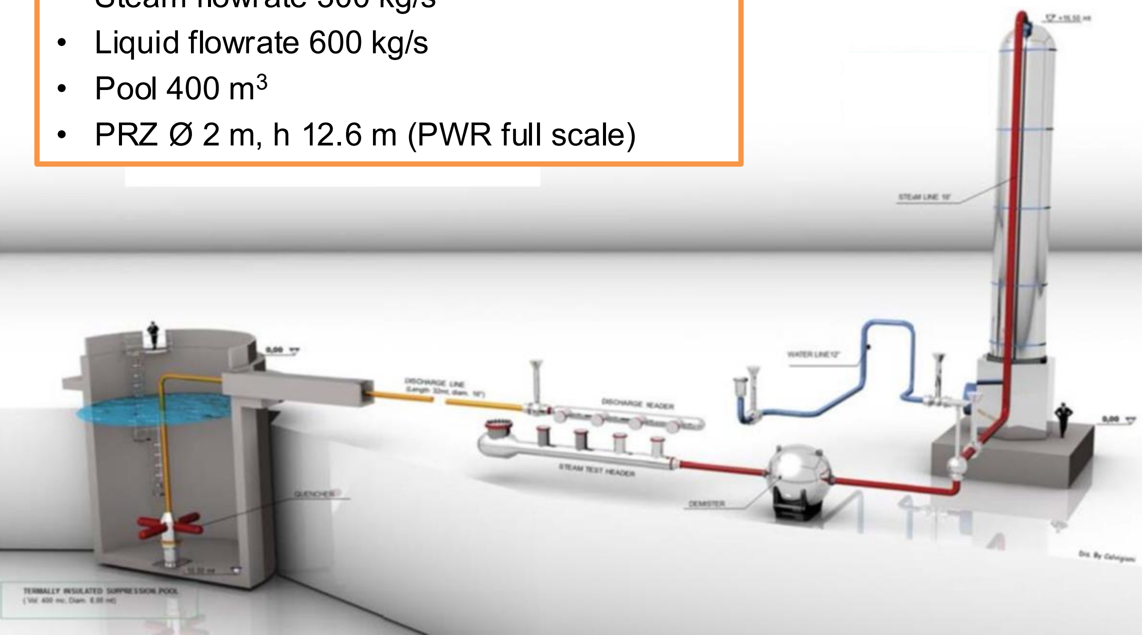
TANDEM: develop methodologies and tools to facilitate the safe and efficient integration of SMRs into smart low-carbon hybrid energy systems.

SASPAM-SA: aims to investigate the applicability and transfer of the operating large LWR knowledge to the integral PWR (iPWR).

VAPORE Facility

Designed for full-scale thermal-mechanical and fluid-dynamic tests on components and systems feeded by saturated water or steam.

- Power 1.4 MW
- Pressure 18 Mpa
- Steam flowrate 300 kg/s
- Liquid flowrate 600 kg/s
- Pool 400 m^3
- PRZ Ø 2 m, h 12.6 m (PWR full scale)



Examples of past experiences

- Safety valves and spargers of Montalto di Castro NPP
- Depressurization system of WH AP600

Activity planning

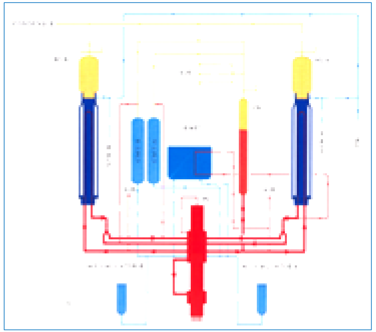
- 2000 stop of operations
- 2024-2026 facility refurbishment and uprating up to 3 MW, funded by MASE
- 2026-2027 sparger test

Experimental support at SIET for safety assessment of SMR

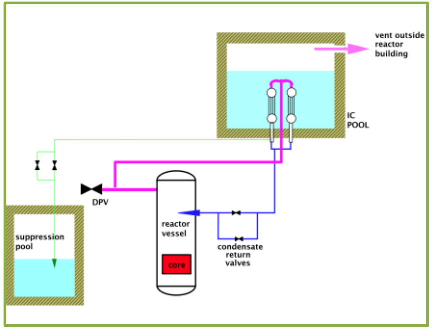
The SIET company has been involved in several experimental campaigns in the last tree decades:

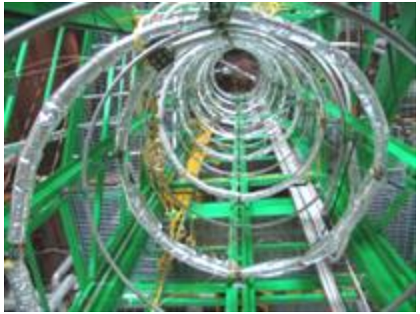
- **SPES2** (1992 - 1994): Integral Test Facility for WEC AP-600 simulation. Full T-H conditions, Volume and power scale ~1/400; Full height.
- **GEST-PANTHERS** (1994 - 1996): Isolation Condenser qualification for GE-SBWR at full scale and full T-H conditions.
- **SPES3-IRIS** (2005-2011): helical coil testing and Integral Test facility design and partial construction

SPES2

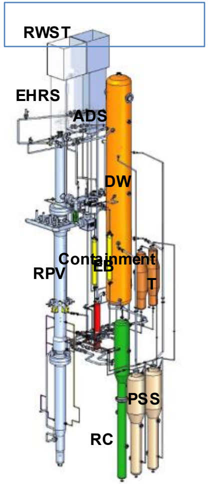


PANTHERS-IC





Helical coils



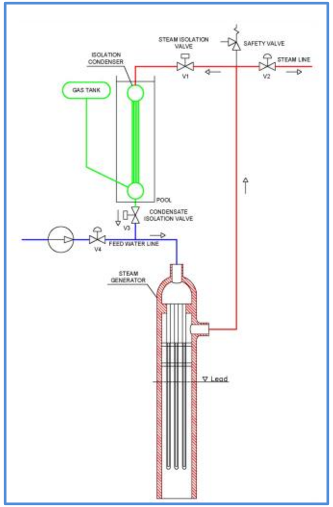
SPES3

Experimental support at SIET for safety assessment of SMR

- **NuScale Power** TF1 and TF2 (2011 – 2015 and 2020 - 2024): helical coil testing and helical coil steam generator mock-up characterization at full scale (reduced number of tube row) and full T-H conditions.
- **NuScale Power** TF3 (2017 - 2024): Helical coil steam generator mock-up at full scale (reduced number of tube row), cold conditions, for Fluid Induced Vibrations investigation.
- **HERO and HERO-2** (2015 - 2017): Testing of bayonet tubes for Liquid Metal Reactor Steam Generator.
- **SIRIO facility** (2018 - 2021) and PIACE European project (2019 – 2022): Testing of a passive "anti-freezing" system for a DHR in Liquid metal cooled reactors and in LWRs.

TF3

TF2 under construction



PIACE

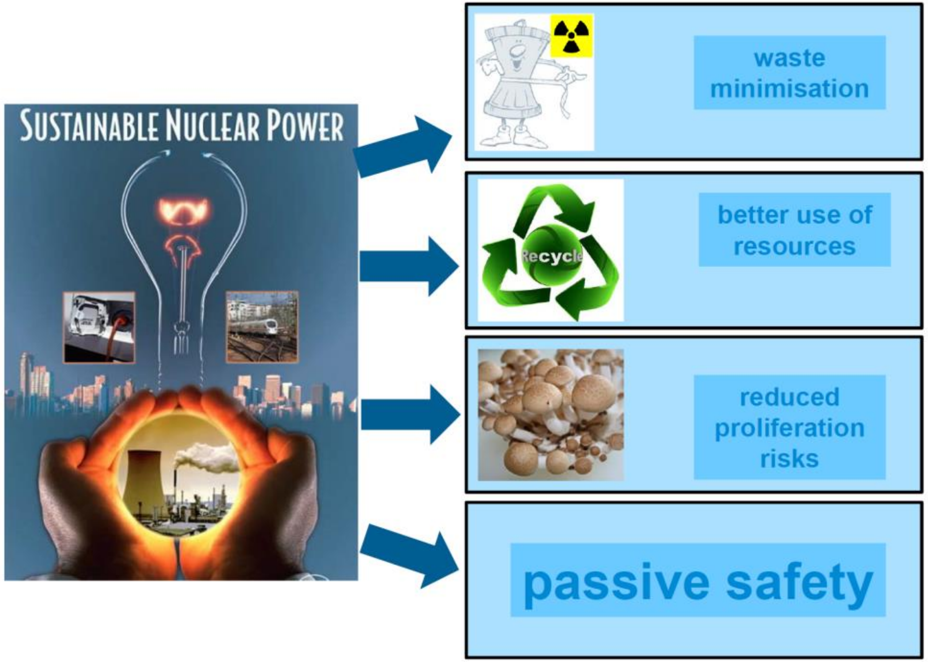
Nuclear Open Issues

- Nuclear Energy
  good but not good enough

- Improvement Safety

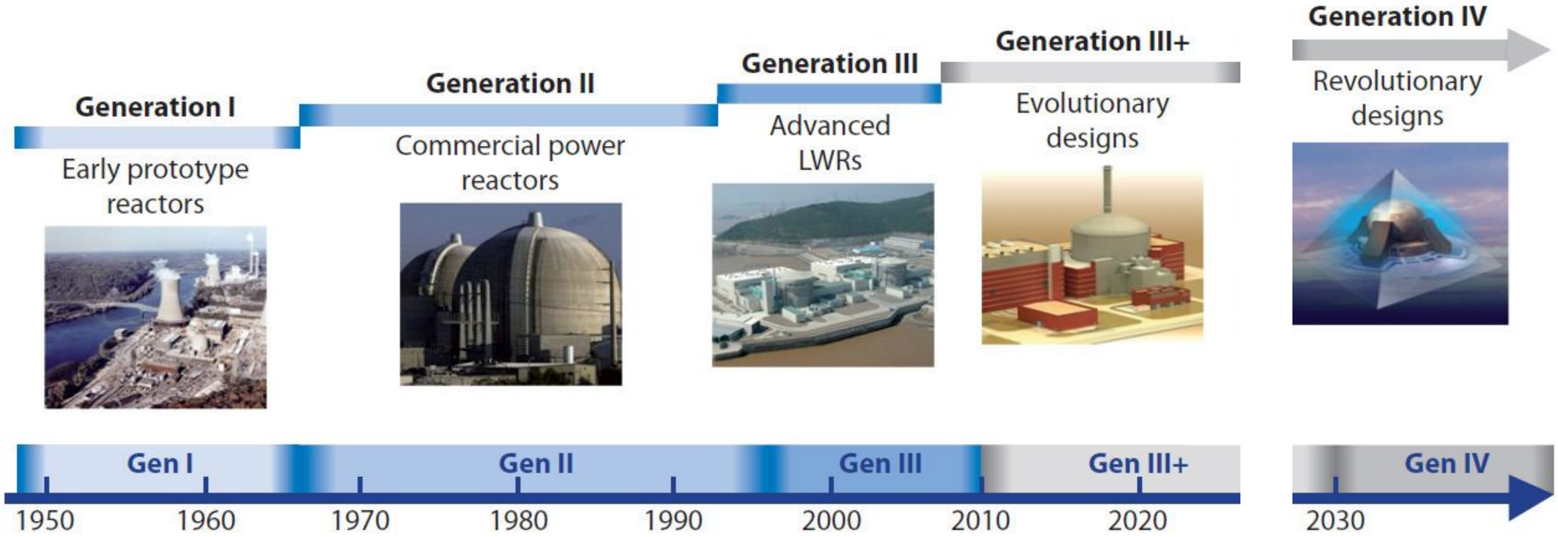
- Waste
  - Too much of it
  - Too long lived

- Economy
  Once through strata
  uses less than 0,5% of the fuel



New Technologies

New concepts: evolutionary… **and revolutionary designs**



Closing the fuel cycle

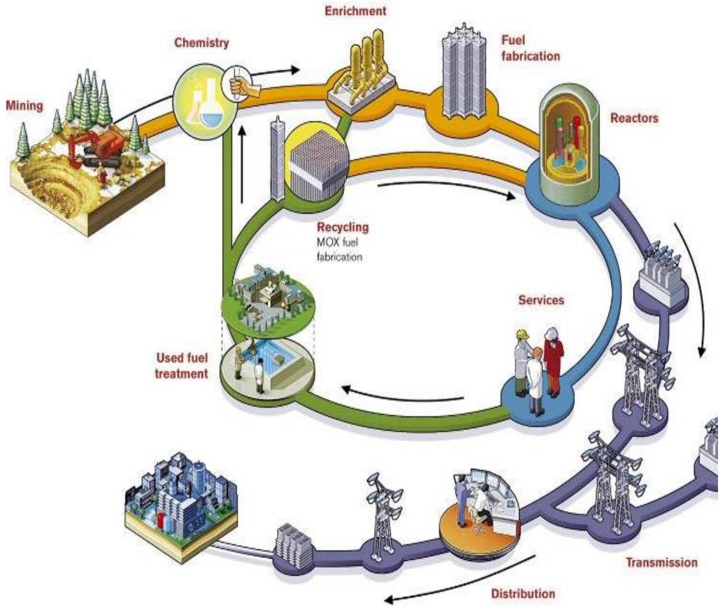
The fission process used in nuclear reactors produces a **number of isotopes that can be toxic to human lives and the environment**.

Since the start of the large scale deployment of nuclear energy, **disposal** of the long lived isotopes has been an issue that has had a priority in most nuclear countries.

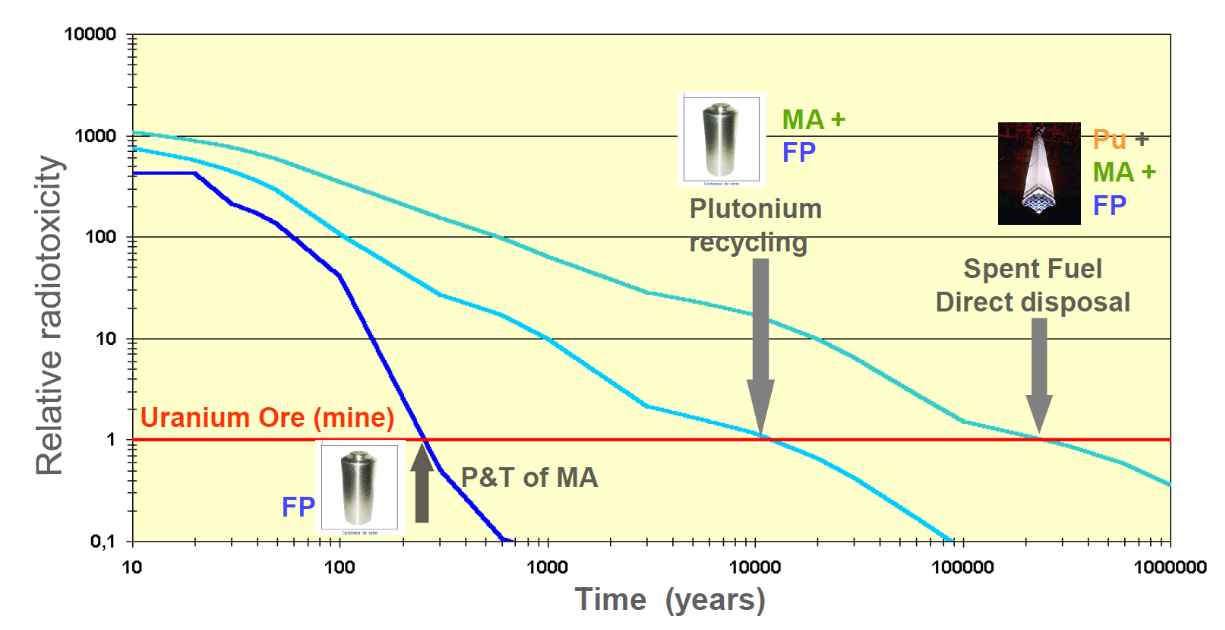
The P&T objectives can be summarized as:

- ❑ Minimization of waste mass sent to a repository,
- ❑ Reduction of the potential source of radiotoxicity
- ❑ Reduction of the heat load in the repository

Fast neutron spectrum reactors are the most adapted technology and offer flexible options for implementation.



Closing the fuel cycle



Recycle of all actinides in spent LWR fuel in fast reactors provides a significant reduction in the time required for radiotoxicity to decrease to that of the original natural uranium ore used for the LWR fuel (i.e., man-made impact is eliminated). From 250,000 years down to about 400 years with 0.1% actinide loss to wastes

Closing the fuel cycle

NUCLEAR MATERIALS INVENTORY (TONS) NEEDED TO PRODUCE 100TWH

		1) Present scenario	2) Near term scenario	3) Long term scenario (after 2040)
		Light water reactors	Lead –cooled fast reactors without Minor Actinides recycling.	Lead –cooled fast reactors with Minor Actinides recycling.
Natural Uranium		2100	10,8** *or* a, b, c	10,44** *or* a, b, c, d
Unused uranium, net generated Pu, Nuclear waste	Depleted Uranium from the enrichment facility.	1900 (a)	–	–
	Uranium from the spent fuel.	184 (b)	–	–
	Pu	2,6* (c)	Negligible	Negligible
	Minor Actinides (Np,Am,Cm)	0,38 (d)	0,36	Negligible
	Fission fragments	13	10,43	10,43

- * It is possible to reduce the plutonium inventory with increased production of Minor Actinides.
- ** Reprocessing losses not included

Source: L. Cinotti, "IW on Innovative Nuclear Reactors cooled by HLM: Status and Perspectives, Pisa 2012

Lead-cooled Fast Reactor

Lead has unique properties for developing a fast reactor

Atomic mass	Absorption cross-section	Boiling Point (°C)	Chemical Reactivity (w/Air and Water)	Risk of Hydrogen formation	Heat transfer properties	Retention of fission products	Density (Kg/m^3) @400°C
207	**Low**	**1737**	**Inert**	**No**	**Good**	**High**	**10580**
Fast neutron spectrum Closure of the fuel cycle	Large fuel pin lattice Low core pressure loss	Primary system at low pressure	No intermediate loop Possible use of low-cost water or air loops for DHR	Reduced risk of plant damage	Reduced risk of fuel cladding overheating	Reduced source term during postulated accidents	No risk of core compaction Core supported by lead

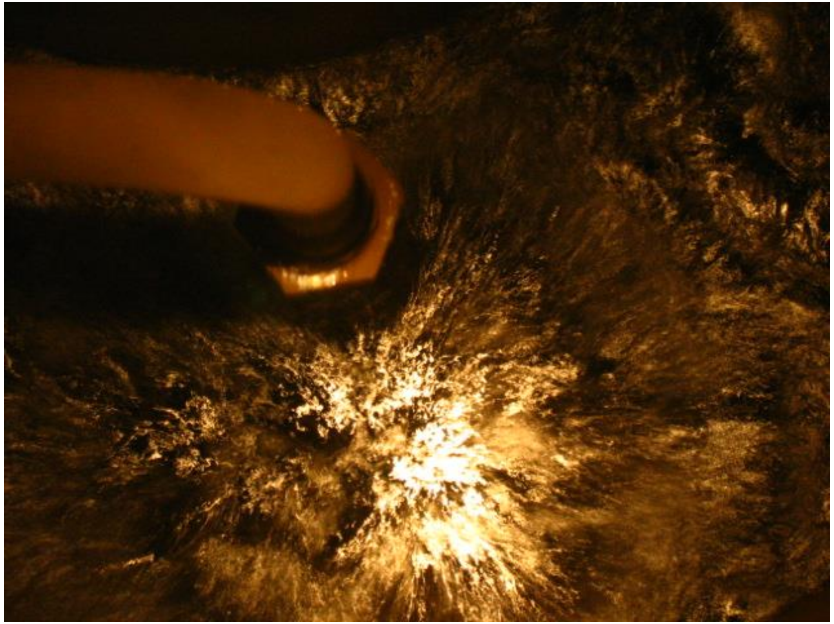
Density (kg/m^3) @400°C	Melting Point (°C)	Opacity	Compatibility with structural materials
10580	327	Yes	Corrosive
But it also has properties that have discouraged some designers			

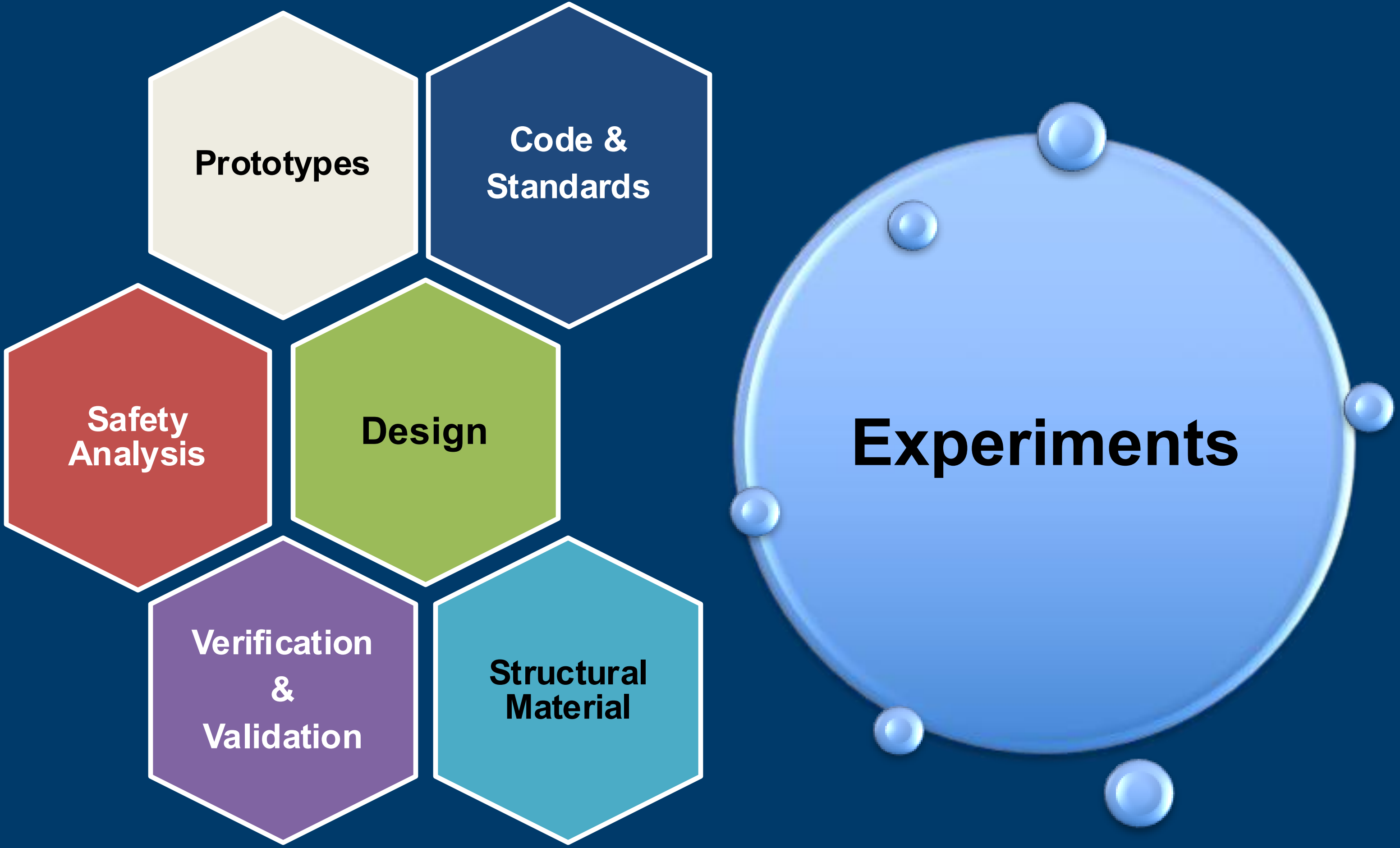
Designers has identified technical solutions to minimize the impact of the unfavorable characteristics of lead and in some cases has also drawn design advantages.

Towards LFR

- The use of a new coolant and associated technology requires a devoted R&D programme.

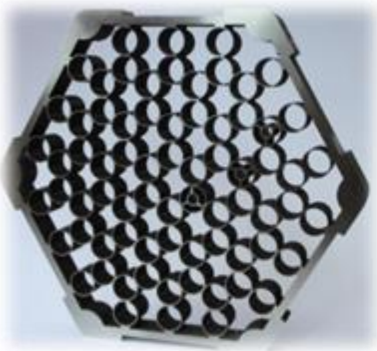
- The R&D programme has to support innovations, through a validation program for new components and systems

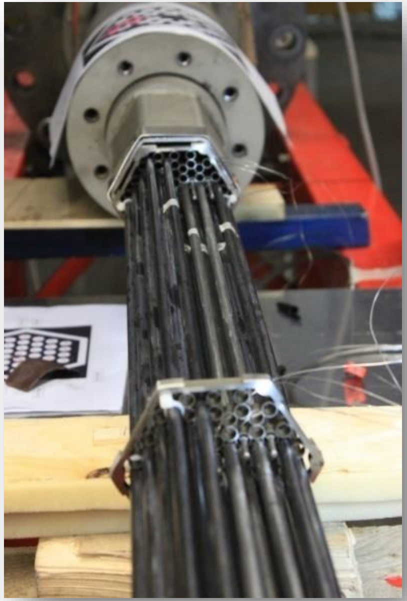



Prototypes
Code &
Standards
Safety
Analysis
Design
Verification
&
Validation
Structural
Material
Experiments

Safety Analysis

Fuel Assembly characterization in transient conditions including flow blockage

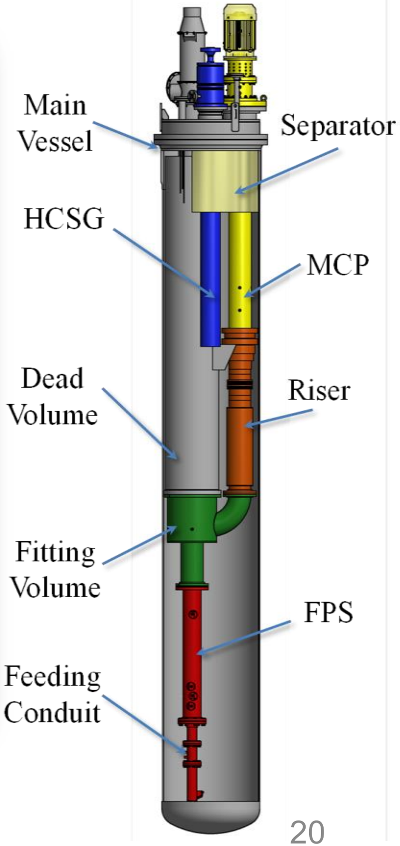




LFR
Integral Tests including SGTR

Integral Test & Component Qualification

- Integral Test Experiments
- OCS testing in large pool
- Component qualification
- SGTR Experiments
- SG & Pump Unit Test



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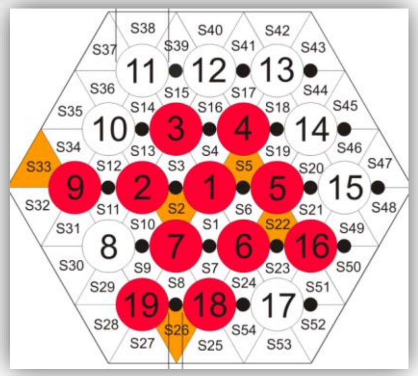
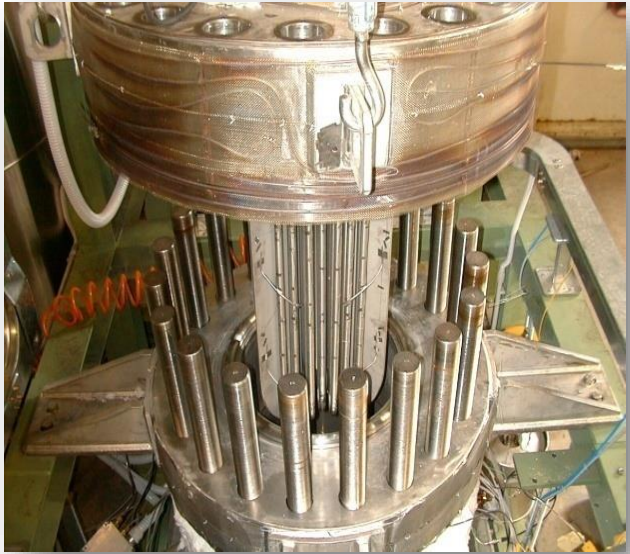
Performance

- HTC measurements
- OCS testing in loop
- Component qualification
- Instrumentation Test



Separate Effect Experiments



- Code Validation
- Component & Instrumentation qualification

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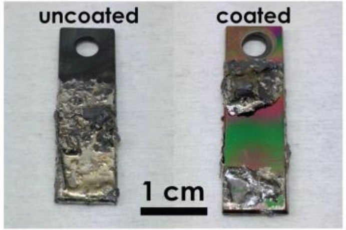
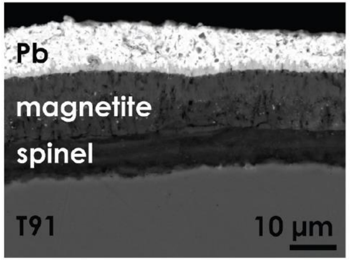
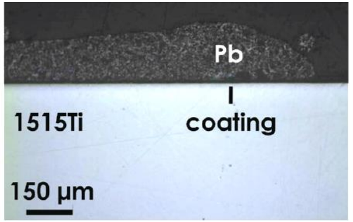
Material Characterization & Coolant Chemistry

- Corrosion test in flowing lead
- OCS testing in loop
- Component qualification
- Instrumentation Test







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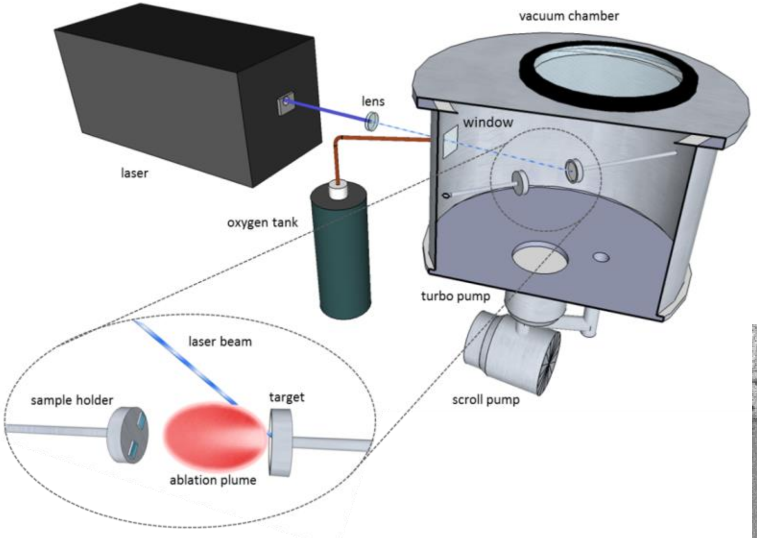
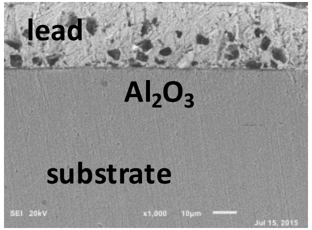
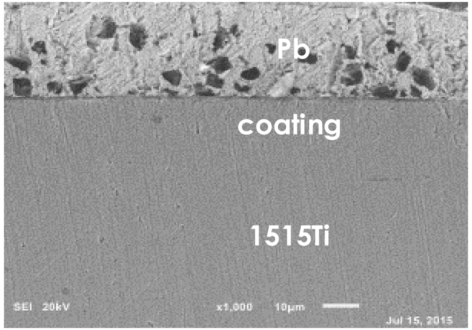
Coating Development

Pulsed Laser Deposition Nanoceramic Coatings (IIT & ENEA)



- ✓ high quality coatings
- ✓ custom process: bottom-up approach
- ✓ process at room temperature

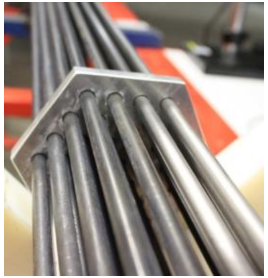


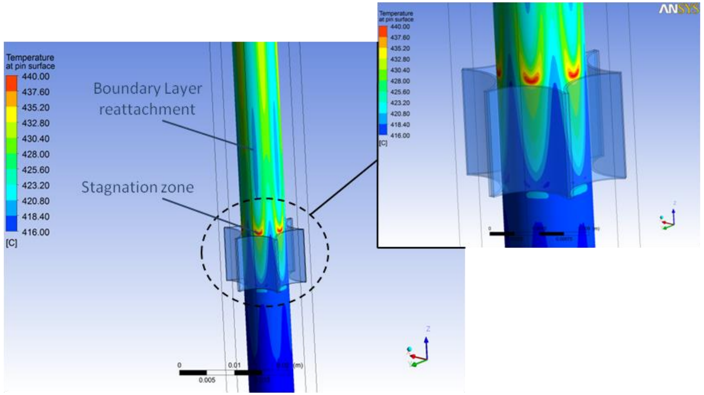


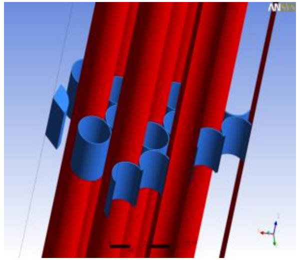
1 μm Al2O3 coating
no buffer layer

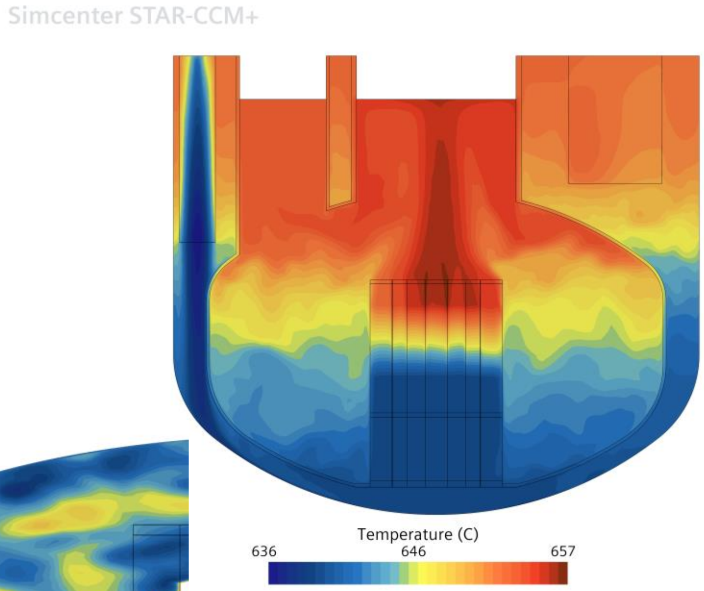
Corrosion tests in static Pb:
550°C -1000 h - $10^{-8}/10^{-9}$ wt.% O
1 μm Al2O3 coating

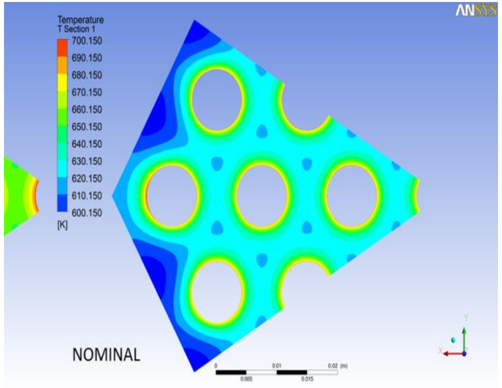
Modelling & Simulations

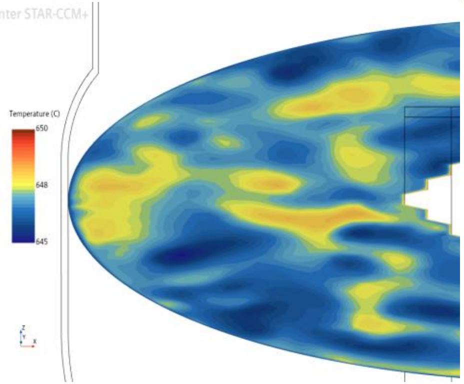






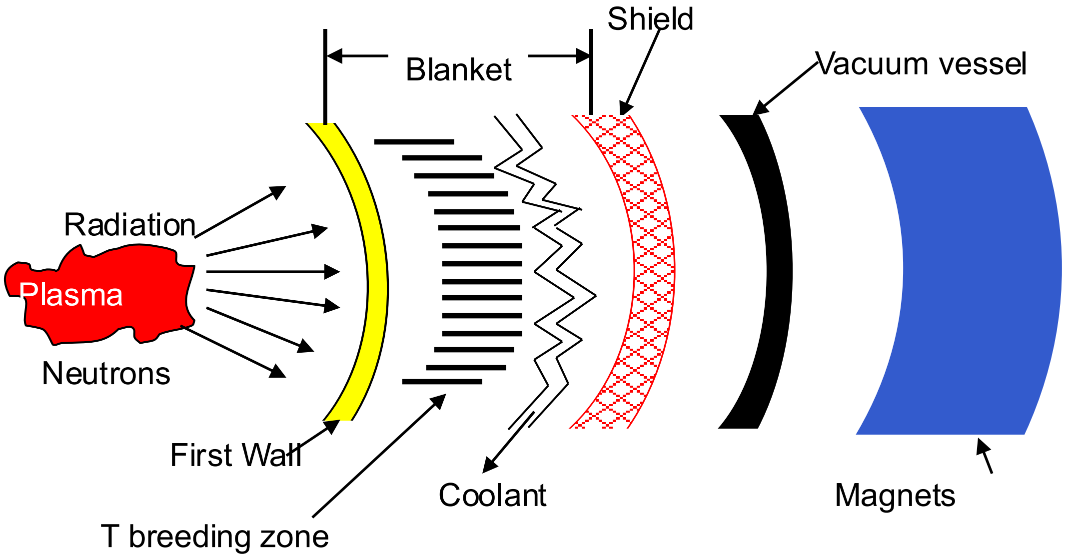






Fusion Technologies

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

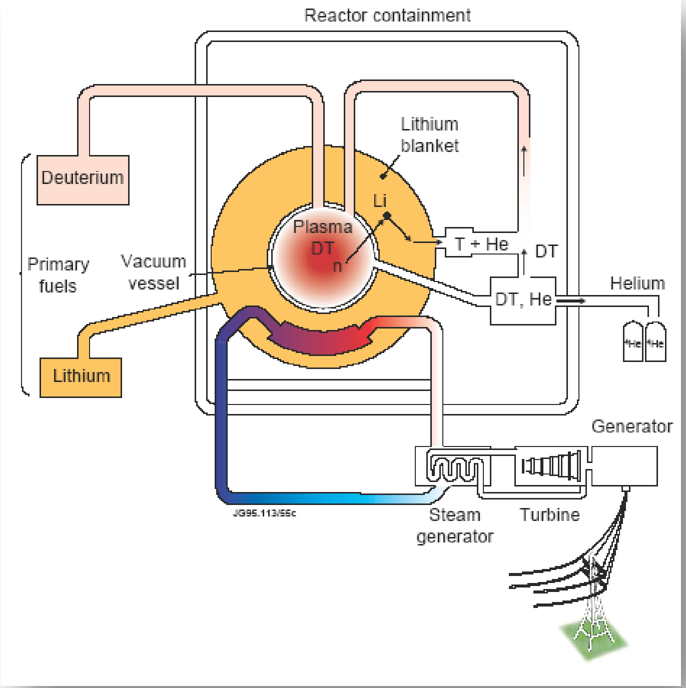
56 kg tritium is required per GW year of fusion power

Breeding reactions in a fusion reactor

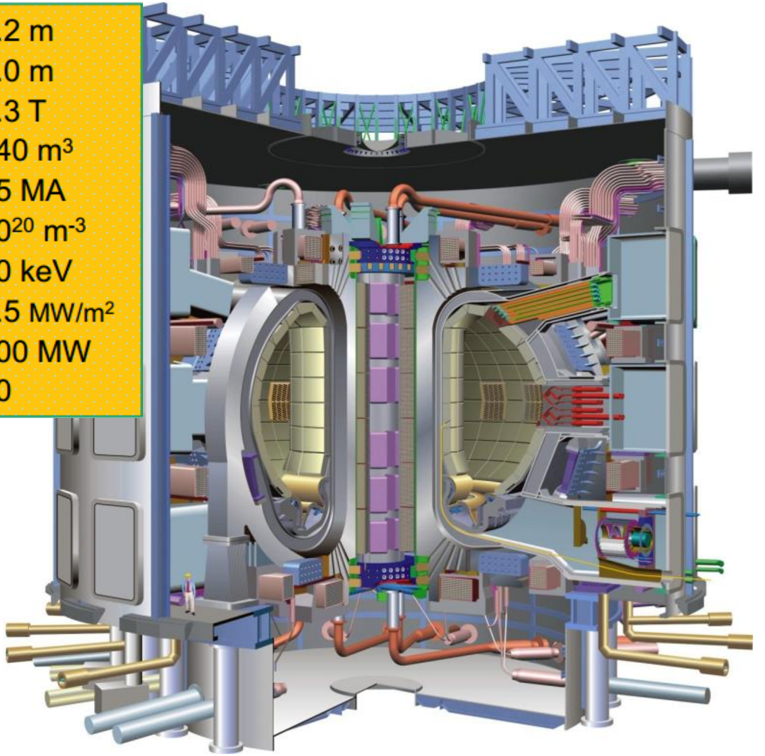
$n + {}^{6}Li \rightarrow T + {}^{4}He$

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

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



What will ITER do?

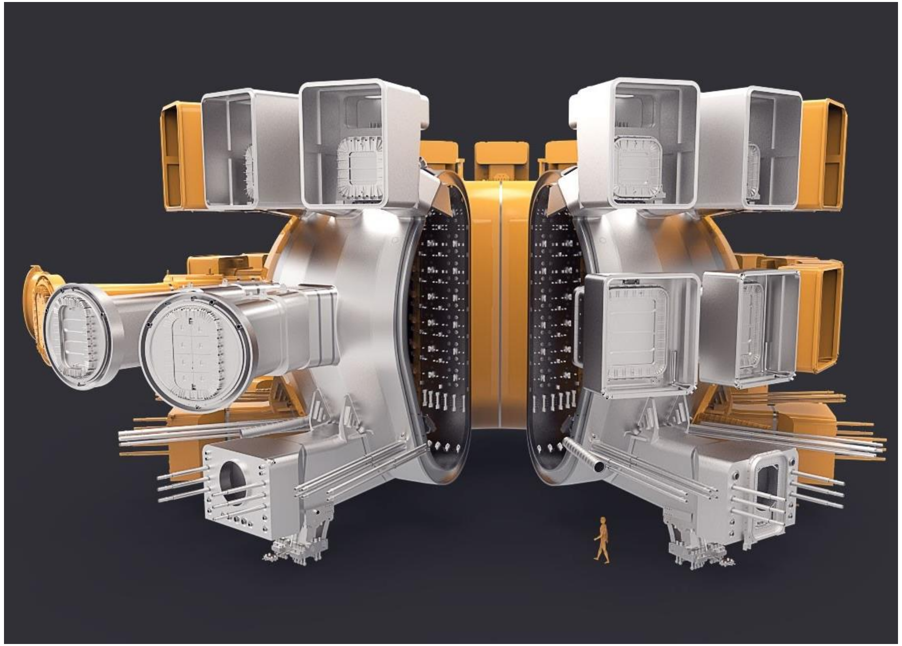
The essential objectives of **ITER** are :

- ❑ Produce a plasma dominated by α-particle heating;
- ❑ Produce **500MW** of fusion power;
  - ➢ The world record for fusion power is held by the European tokamak JET is 16 MW, total input power 24 MW (*Q=0.67);*
- ❑ Produce a significant **fusion power factor** Q≥10
  - ➢ 500 MW of fusion power from 50 MW of input power, for long pulses (400-600 s)
- ❑ Demonstrate **integrated operation of technologies** for a fusion power plant (i.e. Superconducting magnets, remote handling,….)
- ❑ Test concepts for a **tritium Breeding Blanket**

Italian Contribution

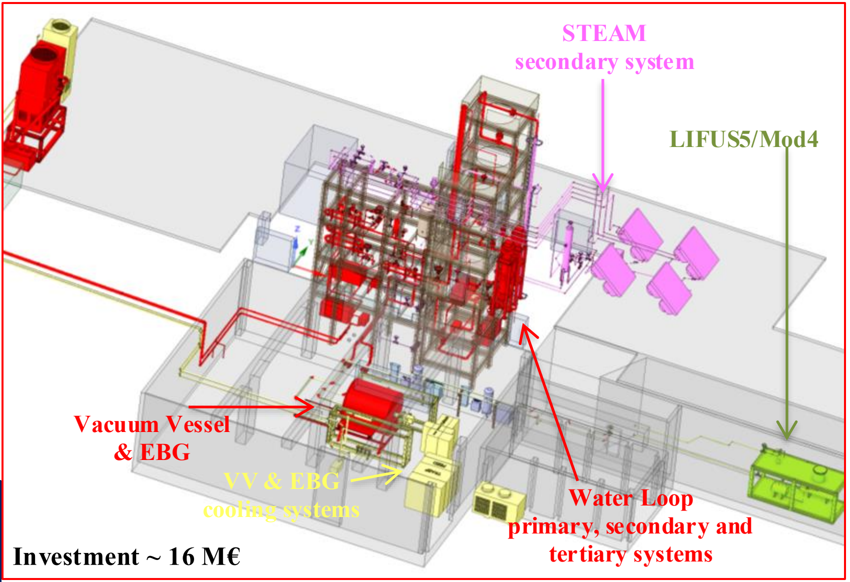
ITER Vacuum Vessel

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 .



W-HYDRA Platform – in construction

- **W-HYDRA** *(Water cooled lithium lead-thermal-HYDRAulic)* **platform includes***:*
  - **WL** (*Water Loop*): WCLL Test Bed and a related water facility (Medium/Large Scale Water Facility)
  - **STEAM** (*STEAM generator test facility*)
  - **LIFUS5/Mod4** (*the 4° version of lead-LIthium FUSion 5 facility*) → integral test facility experiment of PbLi/water reaction scenarios



W-HYDRA platform under construction – planned at C.R. Brasimone by 2025

W-HYDRA is a large experimental infrastructure (3.1 MW heating power, 18.5 MPa pressure, 25m in height)

- Strategic for the development of the TBM, the Breeding Blanket and the Balance of Plant of the ITER and DEMO reactors
- Unique in the international panorama, it will be able to support the design, technology and licensing of ITER's Water Cooled Lithium Lead TBS
- Flexible: it can be used for testing activities related to the Fusion field and beyond, thanks to the availability of an 800kW Electron Beam Gun and of a 25 m^3vacuum chamber

Experimental activities scheduled are:

- ✓ WCLL BB First Wall mock-up in **WL with EBG**
- ✓ WCLL BB Manifold mock-up in **WL**
- ✓ WCLL BB SG pulsed operation in **STEAM**
- ✓ WCLL BB "in-box-LOCA" in **WL+LIFUS5/Mod4**

PbLi-Tritium extraction technologies

IELLLO facility

TRIEX-II facility

HyPerQuarCh II device

PAV internals – Nb tubes

GLC Mock-UP

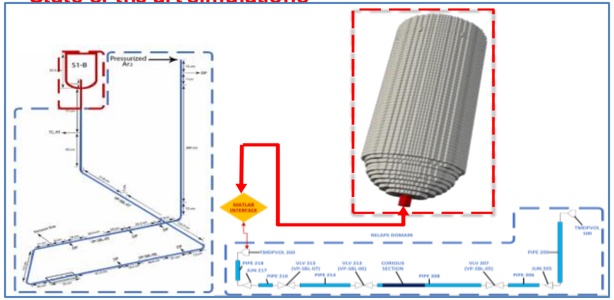
- TRIEX-II facility – H isotopes extraction from PbLi – Testing of Gas Liquid Contactor (**GLC**) and Permeator Against Vacuum (**PAV**)
- HyPerQuarCh II device – Studies of H isotopes solubilities in PbLi
- HPS sensor – for monitoring/measuring the H isotope concentration in PbLi and tested/calibrated in stagnant conditions (HyPerQuarCh II) and fluent conditions (TRIEX-II) – developed @ ENEA
- Testing of industrial and prototypical instrumentations in PbLi (IELLLO)
- Supporting the PbLi loop design, testing the components, operating procedures and the industrial and prototypical instrumentations in PbLi (IELLLO)

ENEA

PbLi-water interaction & Code Development

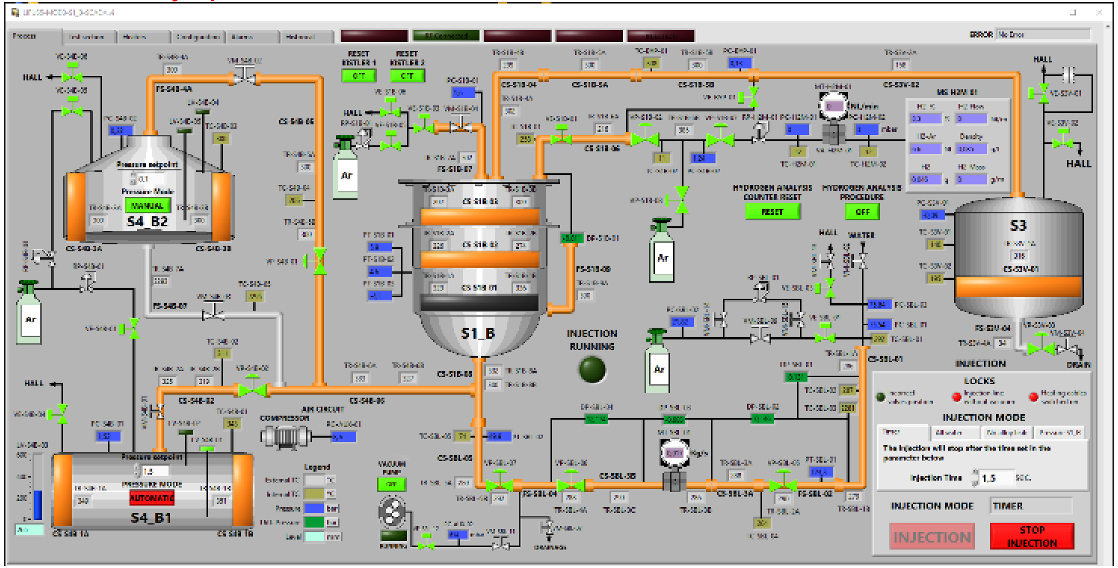
- ❑ Separate Effect Test Facility **LIFUS5/Mod3** aimed at generating the experimental database for codes' development and validation during PbLi and water interaction (chemical reaction process, first pressure peak)
- ❑ State of the art computational capabilities in simulating complex multi-fluid/multi-phase accident scenario

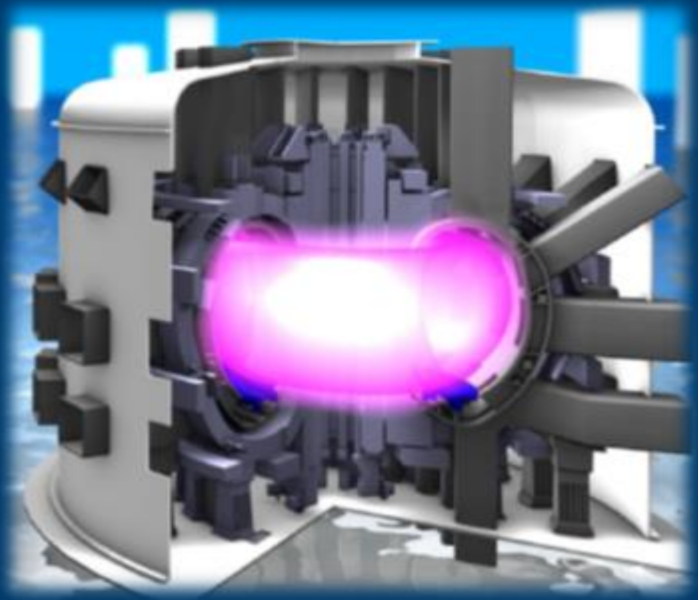
State of the art simulations



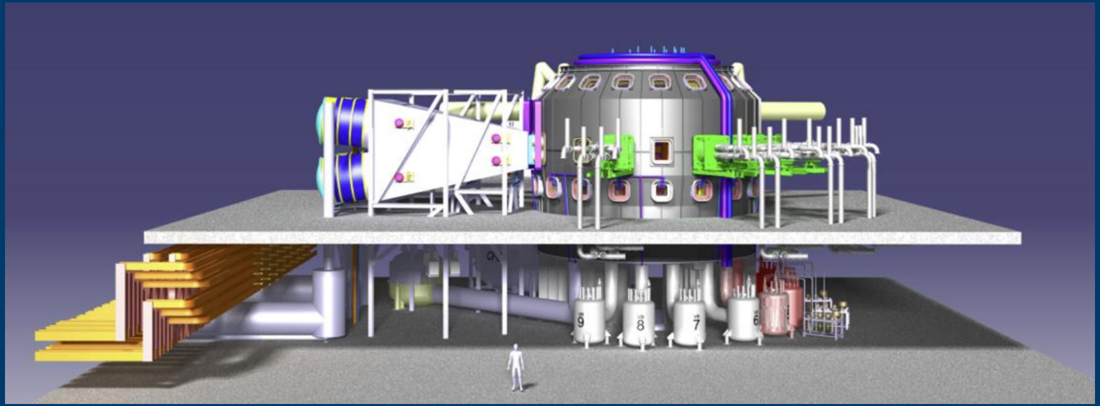
LIFUS5/Mod3 facility

LIFUS5/Mod3 synoptic





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**.

ENEA

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