REAL SOCIEDAD ESPAÑOLA DE FÍSICA
XXXII Bienal de Física
y 19º Encuentro Ibérico de Enseñanza de la Física

Centro Nacional de Tecnologías para la Fusión
(ICTS TechnoFusión)

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(on the behalf of the TechnoFusión Team)

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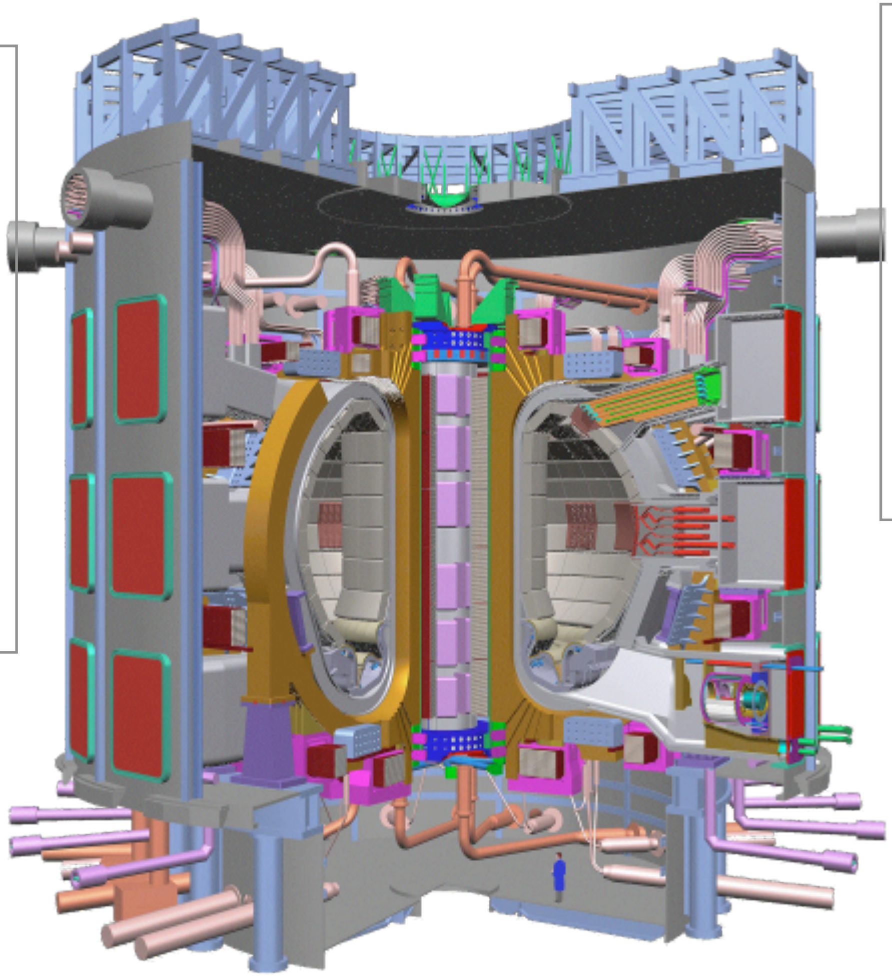
ITER: the next step

Objectives:

Demostrate scientific feasibility of fusion as energy source

- Energy gain Q>10 during 500 s
- Q> 5 during 1500 s

Technology tests (materials, breeding blanket modules…)

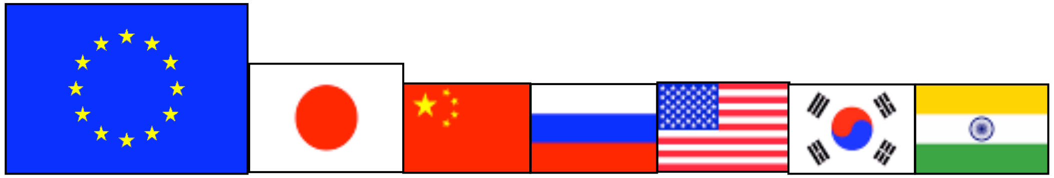


parties:

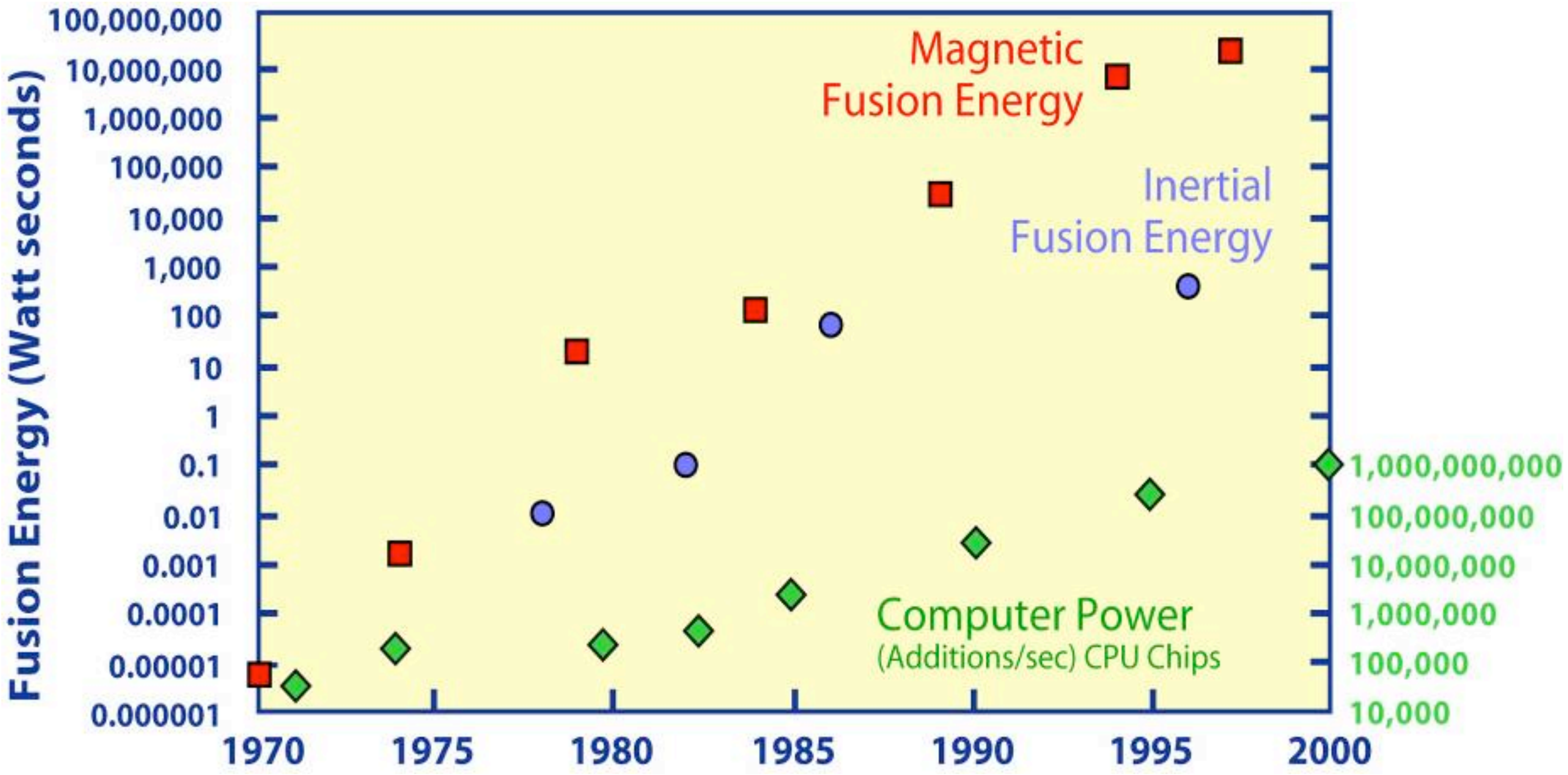
Europe
Japan
China
Russia
US
Korea
India

Cost: 5000 M€ (2001)

Construcción: 2008-18



Progress in fusion research

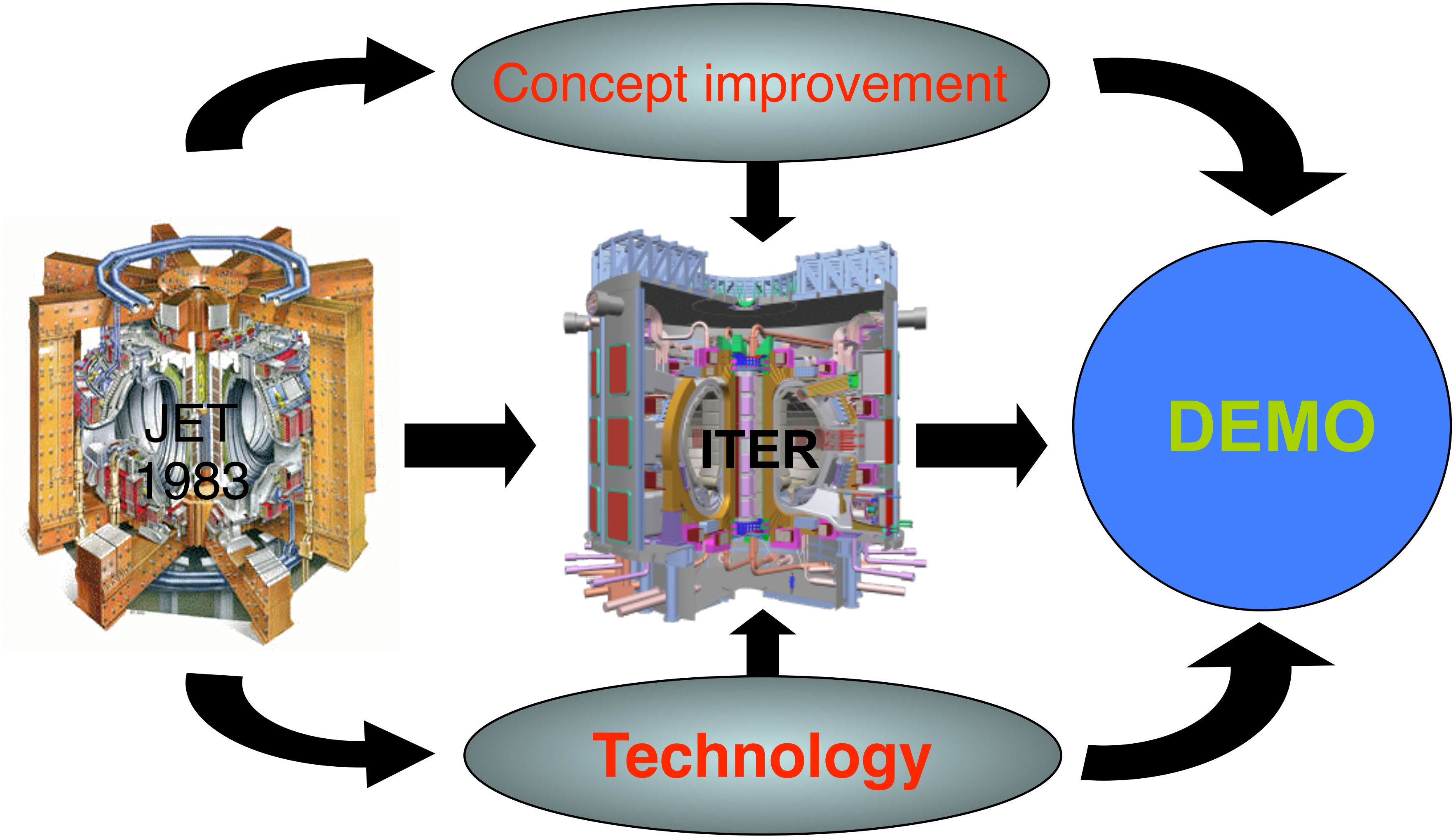


ITER will demonstrate scientific feasibility of Fusion as energy source but it will still remain:

-Physics: steady state
B field optimisation (cost)
2nd generation reactors (stellarators)

-Technology Materials
Tritium self sufficiency
Availability (24x7)
Maintainability

Fusion strategy



Concept improvement

JET
1983

ITER

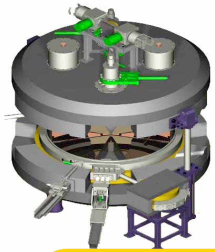
DEMO

Technology

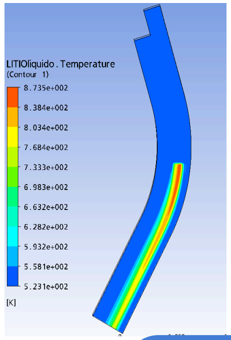
TechnoFusión

- The Regional Government of Madrid and the Spanish Science and Innovation Ministry projects the construction (by means of a Consortium) of the National Centre of Fusion Technologies (TechnoFusión), in Madrid (Spain), based on the technical expertise from CIEMAT, UPM, UC3M,UNED
- Focus on long-term technologies (ITER operation and DEMO): materials and remote handling, with emphasis on radiation effects on different technologies
- It will be included in the Spanish Map of ICTS Facilities. It will be open to Spanish, European and International users
- The coordination with the European Fusion Programme must be assured
- Focus in Fusion Technology, but it can be of interest for many other scientific and technological activities (fission, ADS and spalation sources, biological sciences, space research, medical applications, isotopes production, nuclear physics…)
- **Encouraged by the European Facility Review Panel**

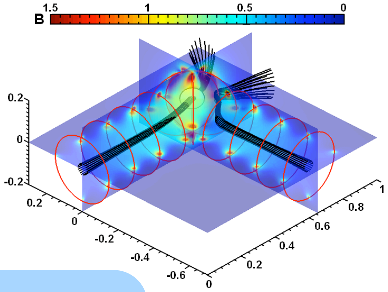
Research & Technological Areas of TechnoFusión



Materials Irradiation

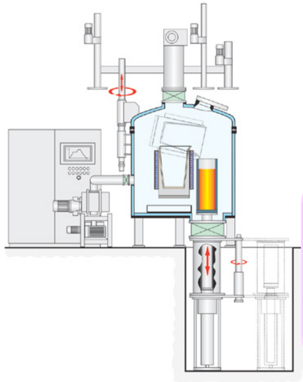


Computational Simulation



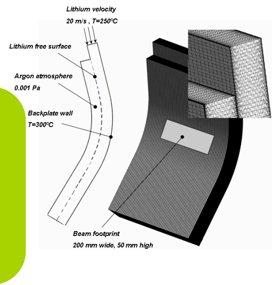
Plasma Wall Interaction

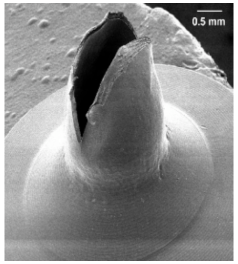
TechnoFusión



Materials Productions & Processing

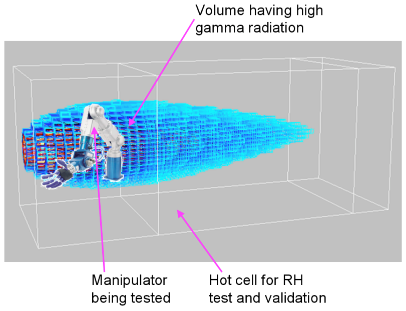
Liquid Metals Technologies



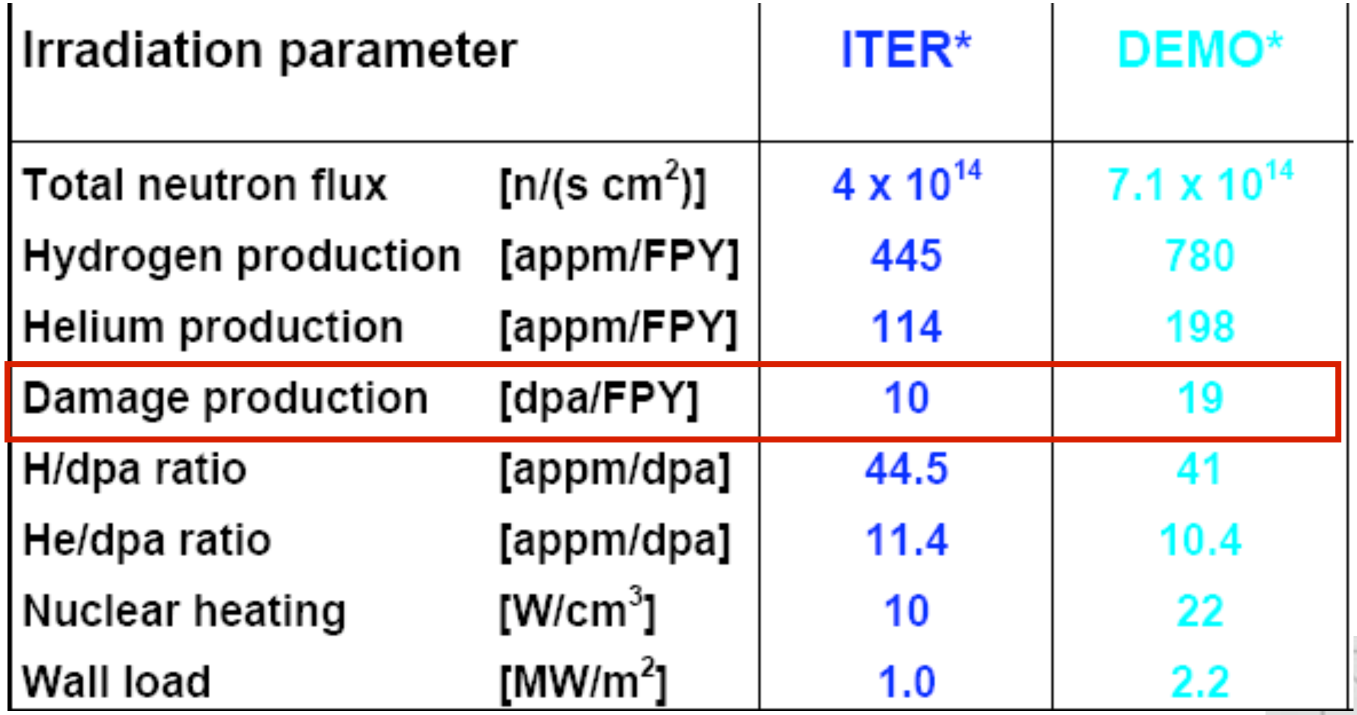


Characterization

Remote Handling



Materials: irradiation damage & activation



Irradiation parameter		ITER*	DEMO*
Total neutron flux	[n/(s cm^2)]	4 x 10^{14}	7.1 x 10^{14}
Hydrogen production	[appm/FPY]	445	780
Helium production	[appm/FPY]	114	198
Damage production	[dpa/FPY]	10	19
H/dpa ratio	[appm/dpa]	44.5	41
He/dpa ratio	[appm/dpa]	11.4	10.4
Nuclear heating	[W/cm^3]	10	22
Wall load	[MW/m^2]	1.0	2.2

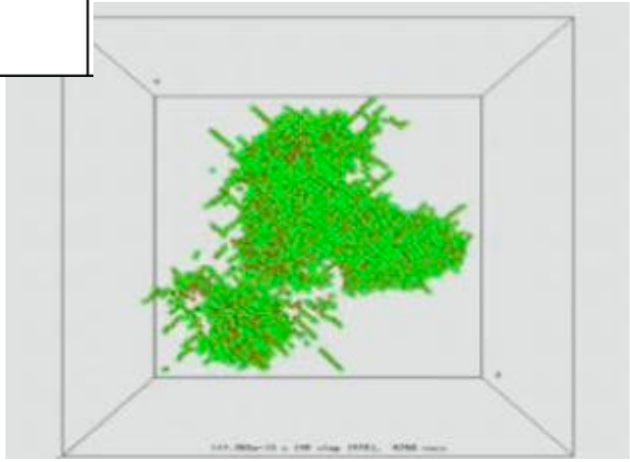
structural damage (dpa´s)

He /H bubbles

Activation

Candidates (structural materials):

- **Martensitic steel “EUROFER”, ODS**
- **Vanadium**
- **SiC/SiC**

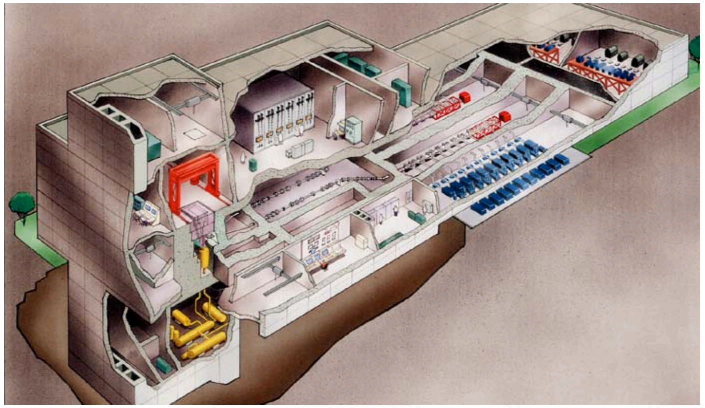


Molecular dynamics calculation of displacement damage due to neutron impact.

Fusion materials R&D

Presently there are no irradiation sources similar equivalent to DEMO

IFMIF Project



Spain heavily involved through the IFMIF-EVEDA Project included in the BA Agreement

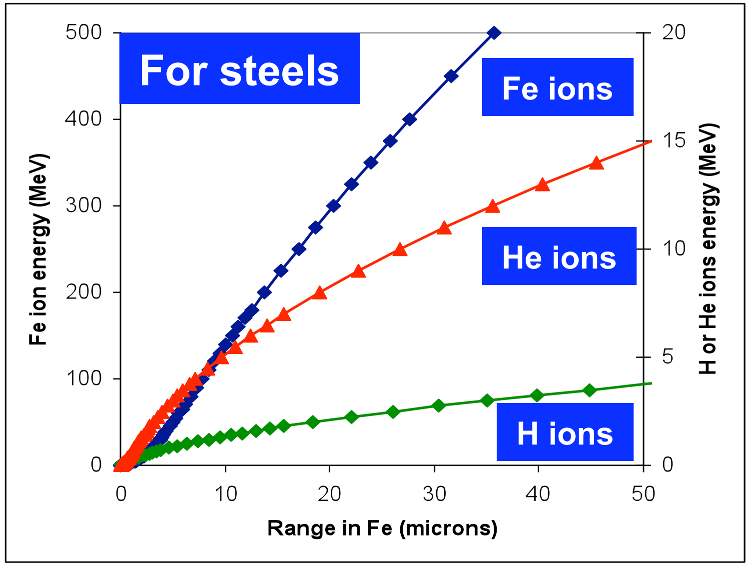
To better understand radiation effects in materials, to be able to make predictions

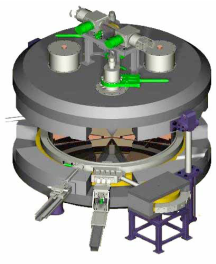
- Systematic studies with alternative radiation sources (fission, spalation, accelerators)
- Development of computational techniques

Techno Fusión

Irradiation with Accelerators

GOAL→ **To reproduce fusion neutron effects –dpa´s, H and He-** in an irradiated thickness of around **20-25 microns** - at least a few grains for most of the materials of interest - **using accelerators**





A set of 3 accelerators to simulate neutron irradiation damage:

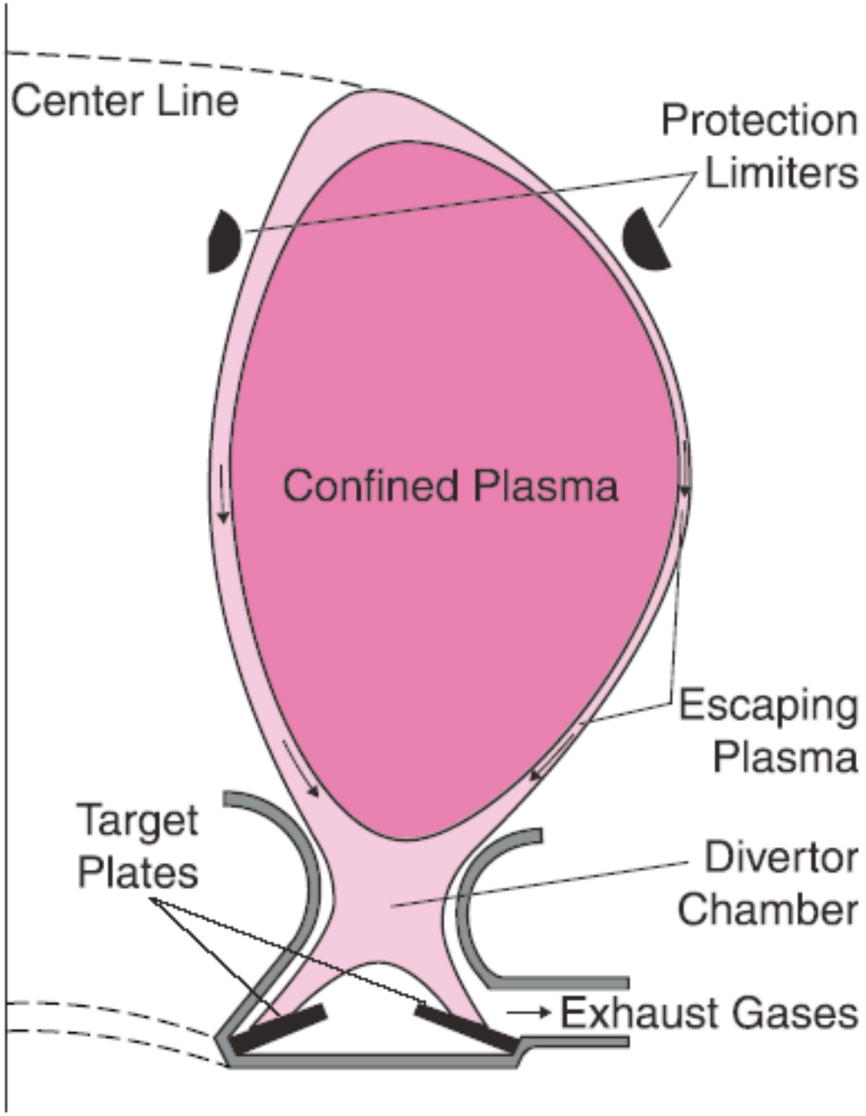
- A cyclotron for **heavy ions** (Fe, W, Si, C, …). Energy: a few hundred MeV (ion dependent)
- A tandem electrostatic accelerator for **He** (and other ions). Energy: around 10-15 MeV
- An electrostatic accelerator for **H** (and other ions). Energy: around 5-10 MeV

Accelerators

		Heavy Ion Accelerator Cyclotron k=110		Linear Accelerator 5 MV		Linear accelerator 6 MV	
Irradiated Material	Depth (µm)	Ion	Energy (MeV)	Ion	Energy (MeV)	Ion	Energy (MeV)
Fe (7.8 g/cm^3)	26.6	Fe	385	H	2.5	He	10
W (19.3 g/cm^3)	10.1	W	373	H	1.6	He	6
C (2.3 g/cm^3)	148	C	96	H	4.5	He	18
SiO_2 (2.2 g/cm^3)	175	Si	337	H	4.6	He	18
SiC (3.2 g/cm^3)	122.4	Si	337	H	4.6	He	18
SiC (3.2 g/cm^3)	122.4	Si	337	D	6.0	He	18

- It is a intrinsically “low activation” irradiation method
- Other type of experiments will be also available (irradiation under magnetic field, 20-40 MeV proton irradiation, dual beam irradiation,…)
- It will be required some components development (beam degrader, neutralizer,…)
- Cyclotron design (isochronos multi-ion, …) is challenging

Thermal load to walls



80% power: 14 MeV neutrons

Neutrons escape isotropically and are absorbed in volume at the blanket-> power to the heat exhangers and turbines.

20% power: 4.3 MeV α´s

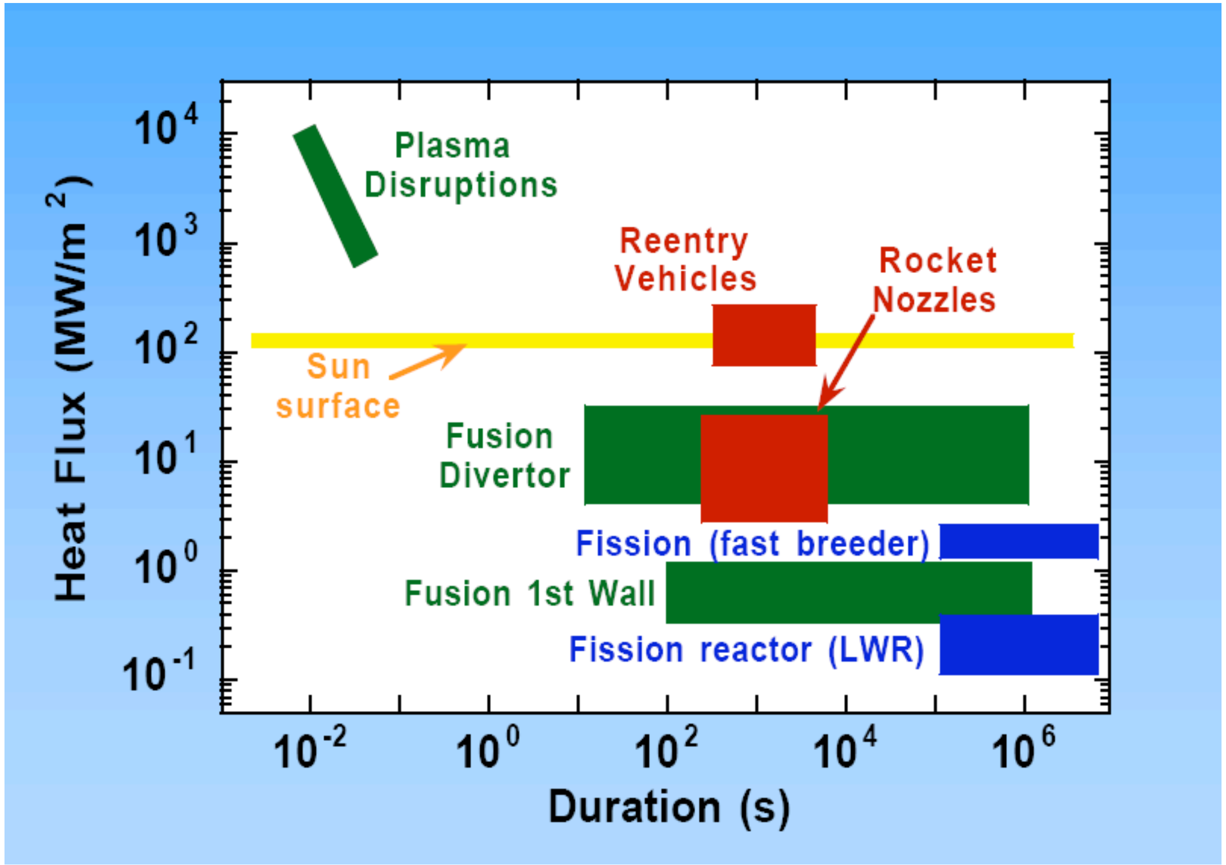
Alphas heat the plasma, maintain ignition and this energy is slowly transported ot the wall

In a reactor:

1000 MW neutrons

200 MW alphas

Materials: thermal load



Alternatives:

CFCs, Tungsten, “wicks” with liquid lithium

PALOMA: A PWI Facility for Reactor Materials Studies

Goals

- To reproduce the real, harsh, environment under which materials will be exposed to the plasma in a fusion reactor (ITER/DEMO):
  - ELMs+Disruption parameters reproduction
  - Capability to study PW effects in materials previously irradiated at the Ion Accelerator Complex with heavy ions + H+ He ("low activation" irradiation) up to DEMO EoL equivalent conditions

Background:

- **Particle fluxes at the divertor in ITER and in reactors:** > 10^{24} ions/m^2.s
- **Transient thermal loads (ELMS and disruptions):** ~ MJ/m^2
- **Temperature between transients:** few 100 ºC (not loaded areas) to1500 ºC (loaded areas)
- **Frequency and duration & of transients:** few Hz to one every several pulses , 0.1-10 ms
- **ITER FW materials:** CFC, W, Be
- **DEMO FW materials:** W, SiC, Liquid metals(?)….
- **Neutron damage:** 1 dpa (ITER),>150 dpa (DEMO)

PALOMA Components

Linear Plasma Device (LP):

- **Cascade arc, superconducting field (1T)**
- **PILOT-PSI design. *Upgrade to larger Beam (FOM Collaboration)***
- **Steady-state, superconductor (commercial available)**
- **UHV pumped (impurity control)**
- **Physics studies and diagnostic development for divertors**

PILOT PSI-like parameters

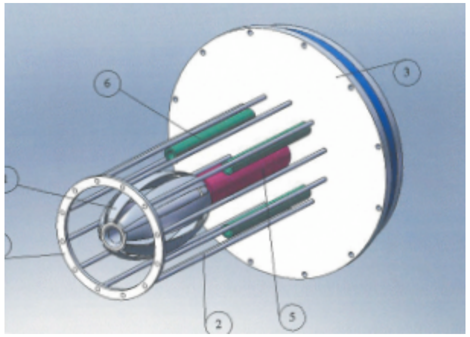
- **Pulsed up to 1.6T (0.4s)**
- **0.2T in steady-state**
- **2 roots pumps with total pumping speed 7200 m^3/h**
- **Pressure 0.1-1 Pa during plasma operation**
- **Power fluxes > 30 MW/m2**
- **Already achieved ITER-like fluxes, first 5 cm of ITER target (5mm SOL) can be simulated**
- **+ beam expansion by B tailoring: Still high flux density and large beam**

Plasma Gun:

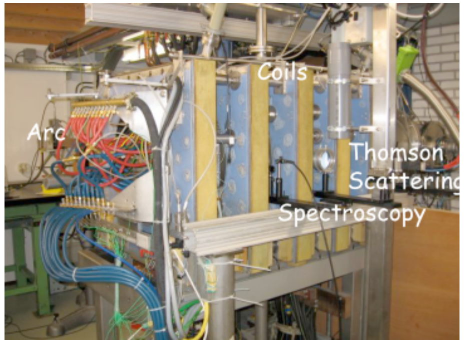
- **Compact QSPA type: Development under collaboration with Kharkov IPP**

QSPA parameters (MJ/m^2 range)

- **Pulsed duration: < 500 μs**
- **Plasma current: < 650 ka**
- **Ion energy: < 1 keV**
- **Electron density: 10^{15} – 10^{16} cm^{-3}**
- **Electron temperature: 3 – 5 eV (< 100 eV at sample)**
- **Energy density: > 2 MJ/m^2**
- **Magnetic field at sample: 1 T**
- **Repetition period: 1- 3 min**

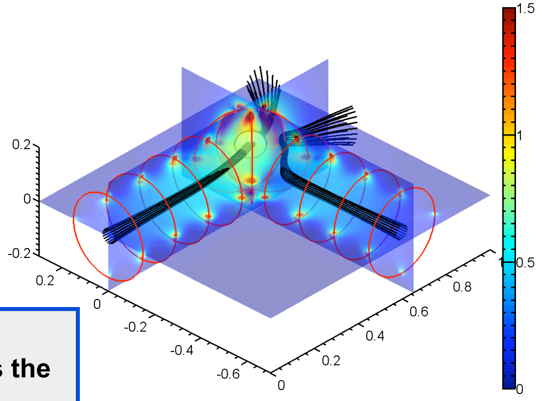


QSPA plasma source

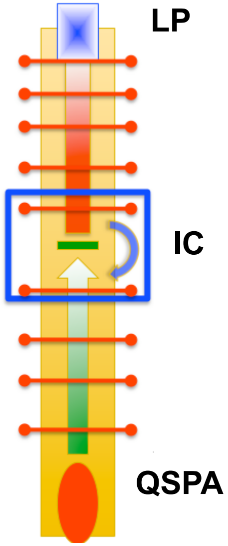


PILOT PSI

Synergistic effects of high power & particle irradiation not tested !!



Perpendicular



Collinear

Interaction Chamber (IC):

- **Change in impact angle**
- **Cooling. Heating of samples**
- **IR+visible cameras…**
- **Transport of samples under vacuum?**

A) Perpendicular

Inversion of the current in one coil allows the switch from implantation to QSPA

Fast switching could be achieve if coupling is made by external coils

Problematic: forces /torque

B) Collinear

Problematic: Fast rotation of sample

Production and Processing Area

- A lab to bridge the gap between research groups and companies (at the level of prototyping)
- Two areas identified:

  I) Advance materials processing techniques (materials development and production)

    - Capability to produce a few tens of kg under well controlled conditions for same materials
    - Selected technique: mechanical allowing from powders (of interest for ODS steels, nano-steels, W alloys, ceramics,…)
    - *Maybe another one (proposed* ***spark plasma****, extrusion or HIP)*

  II) Advance manufacturing techniques (welding, joining, shaping techniques)

MATERIALS

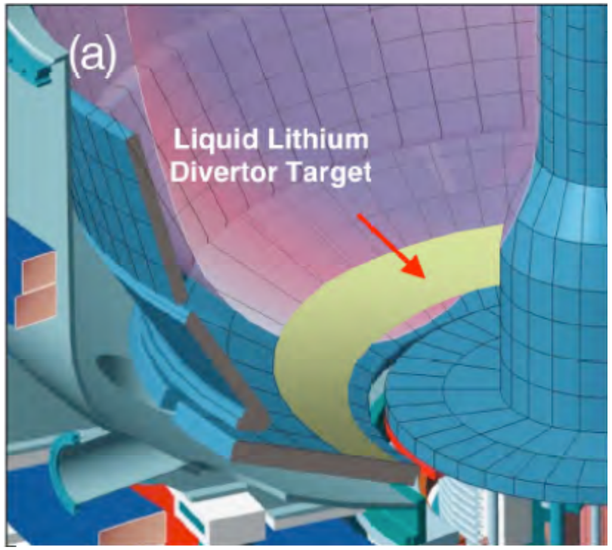
- **ODS and nanostructured steels**
- **Fe-Cr alloys**
- **W alloys (ODS & non-ODS)**
- **Multifunctional materials; FGMs**
- **Protective coatings**

TECHNIQUES

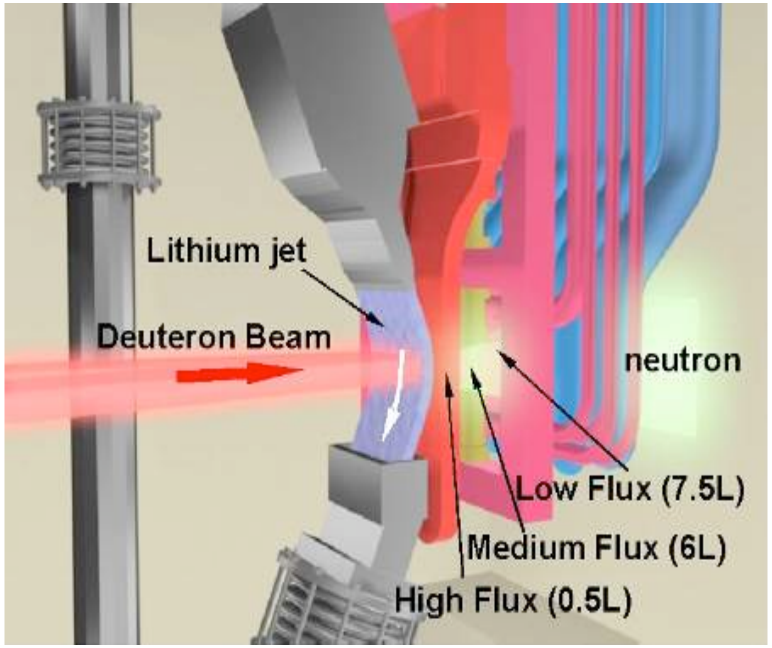
- **VIM (vacuum induction melting)**
- **HIP (hot isostatic pressing)**
- **SPS (spark plasma sintering)**
- **Sintering in H_2**
- **Vacuum Plasma Spraying (VPS)**

Liquid Metal Experimental Area

- **The liquid metal laboratory will consist of a liquid lithium loop devoted to the development of liquid metal technology**



Li of interest as first wall, divertors, limiters for fusion reactors

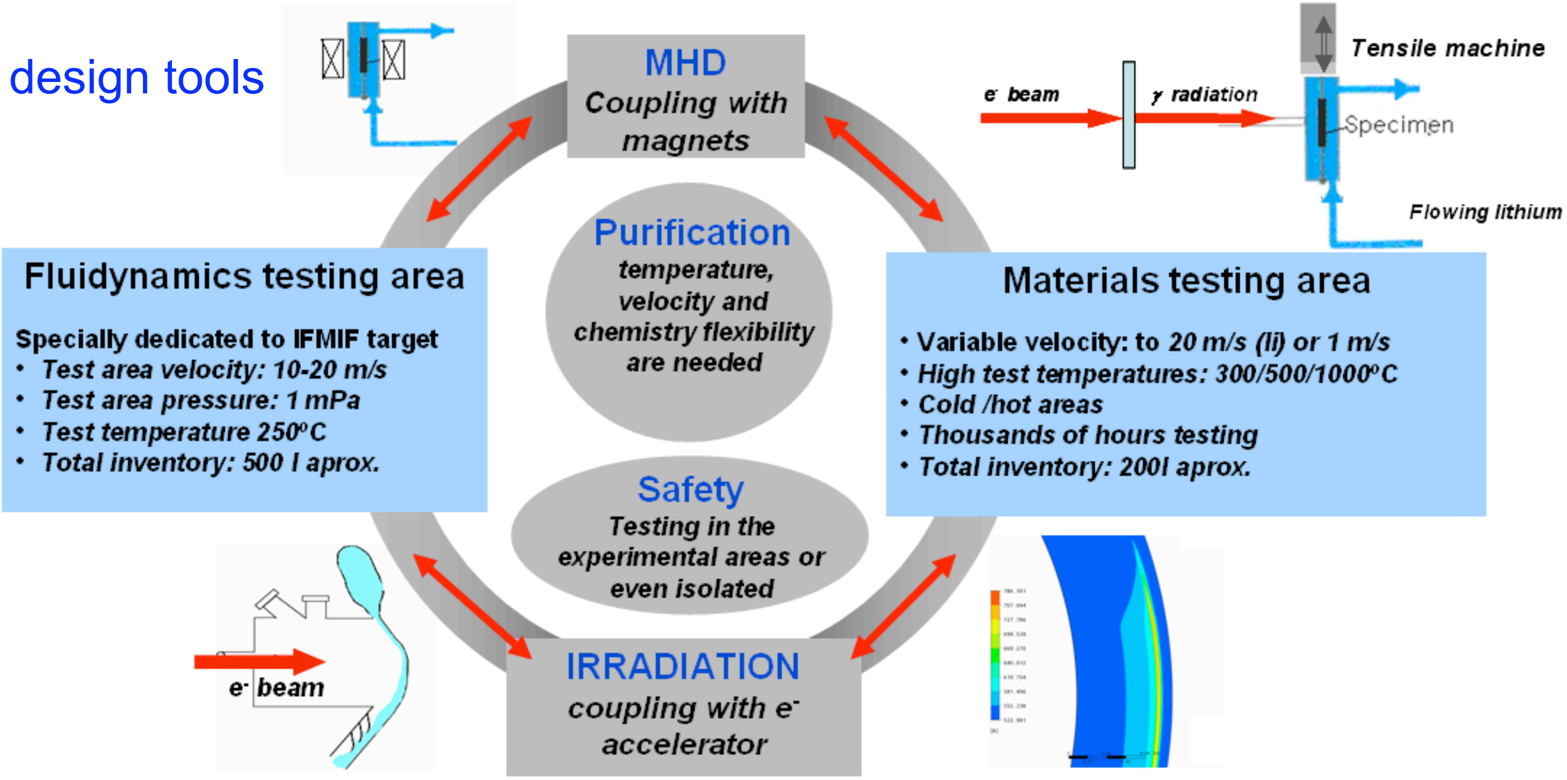


Liquid lithium is used as target for IFMIF

Liquid Metal Facility Main Objectives

The acquisition of the key technological information required to use the liquid metals in fusion technologies, in subjects such as:

- Free surface behaviour (including with energy deposition using electrons from one accelerator and vacuum conditions)
- Corrosion (including under ionizing irradiation using electrons from the electron accelerator)
- MHD effects (using a magnetic field)
- Purification of lithium
- Safety
- Validation of design tools



MHD
Coupling with magnets

Purification
temperature, velocity and chemistry flexibility are needed

Safety
Testing in the experimental areas or even isolated

IRRADIATION
coupling with e^- accelerator

Fluidynamics testing area

Specially dedicated to IFMIF target
- *Test area velocity: 10-20 m/s*
- *Test area pressure: 1 mPa*
- *Test temperature 250ºC*
- *Total inventory: 500 l aprox.*

Materials testing area
- Variable velocity: to *20 m/s (li) or 1 m/s*
- *High test temperatures: 300/500/1000ºC*
- *Cold /hot areas*
- *Thousands of hours testing*
- *Total inventory: 200l aprox.*

Characterization Techniques

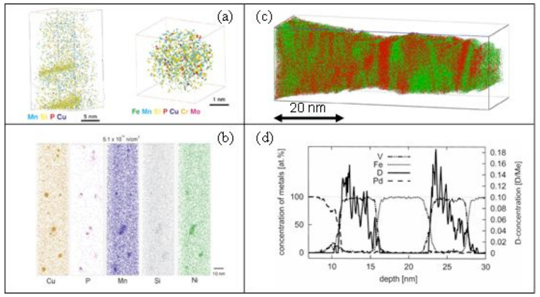
- **Supporting the other TechnoFusión Facilities**

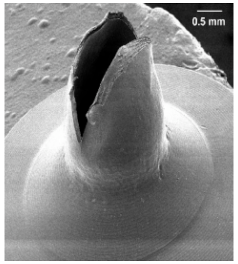
- This aspect will be critical to assure the success of the facility. Especial attention to both **in-situ** and **ex-situ** characterization techniques.

- Focus on the development of **mechanical properties** measurement techniques of the damaged region in-situ and ex-situ (uniaxial tension, small punch, shear punch, nanoindentation, FIB)

- Focus on **microstructure characterization** of the damaged region, mainly ex-situ (SIMS, APT, FIB, TEM+EELS, …)

- Focus on **physical properties** characterization of the damaged region in-situ and ex-situ (resistivity, luminescence, absorption, thermal conductivity, diffusion,…)





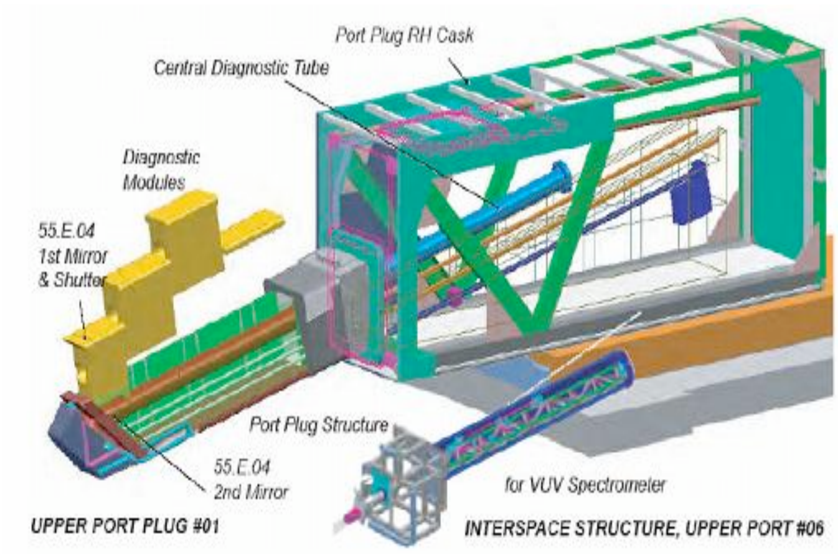
Remote Handling Facility

Experimental Set-up

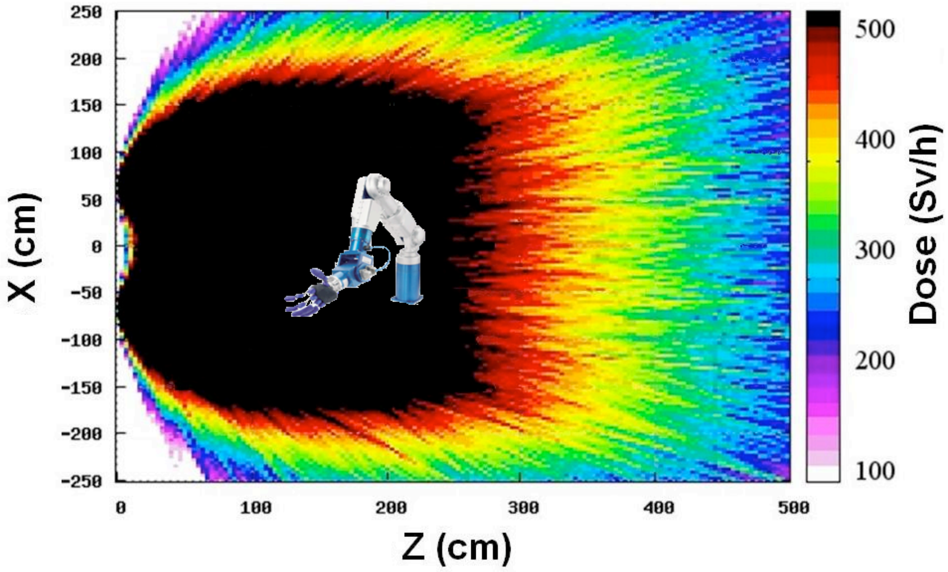
- **Remote Handling Design and Development Test Facility** for Large Prototypes, with RH infrastructure needed to host future possible facilities (TBMs RH, ITER Diagnostic Port-Plugs, IFMIF RH procedures, DEMO procedures…)
- **Remote Handling Irradiation Test laboratory** for qualification of RH tools and machines in an uniform ionizing field equivalent to ITER-DEMO (e^- at 10 MeV producing **gammas at 100-500 sv/h**)

Objectives

- **Test RH under irradiation ITER-IFMIF-DEMO like conditions**
- **Radiation-Hard new tools & components development**



Gamma field inside the irradiation test room



Outline and schedule

- Conceptual design: **2009**
- Detailed design and prototyping: **2010-2012**
- Buildings and Commercial Hardware: **2011-2013**
- Complex Hardware: **2011-2014**
- Installation and Commissioning: **2012-2015**

It is foreseen a development in several phases

Provisional priorities (they should be agreed with the EU Programme, taking into account availability of equipments, complexity, possible users,…) :

First phase

- Some characterization techniques (SIMS, Atomic probe), low energy accelerators, Remote Handling Lab, Materials Processing Lab, QSPA

Second phase

- Other characterization techniques, high energy accelerator, liquid metal loop, complete PWI

TechnoFusión short term milestones:

Today: Scientific Case Report issued in August 2009

Before end of the year: 1) International Technical Review
2) Pre-engineering design