The Multi-Ion-Irradiation Laboratory of TECHNOFUSIÓN Facility and its Relevance for Fusion Applications

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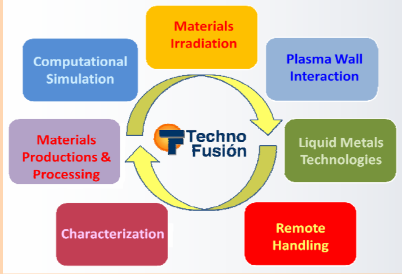
TechnoFusión

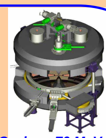
- ITER, IFMIF and DEMO construction demands research projects for the **development of fusion reactors materials**
- The Regional Government of Madrid and the Spanish Science and Innovation Ministry projects the construction of **the National Centre of Fusion Technologies** (**TechnoFusión**), in Madrid (Spain)
- The Research Centre will include a set of facilities to provide **new tools to the nuclear fusion technologies**
- **Open to Spanish, EU, and International users**
- **R&D of TechnoFusión** will be focused on seven technological area, emphasizing:
  - Studies of the radiation effects on structural and functional materials using simultaneous ions
  - The evaluation of plasma interactions with first wall materials
  - Development of advanced manufacturing technologies and corresponding materials characterization
  - Improvement of liquid metal technologies
  - Tests of robotics and automation for Remote Handling (RH) including under irradiation operation



MATERIAL IRRADIATION AREA

- To **reproduce fusion neutron effects** –DPA, H and He- in an irradiated thickness of around 20-25 microns **using accelerators**
- Simulation of fusion-like radiation effects on sample materials by means of three ion accelerators (displacement + transmutation):
  - **Two electrostatic accelerators, tandem-type, for light ions such as He and H**
  - **One heavy-ion cyclotron** (Fe, W, Si, C or high energy H^+, k = 110) for implantation
- **Experiments: (1) Triple, dual and single beam irradiation. (2)** Inclusion of **magnetic field (5-10T) during irradiation. (3) Time and temperature** effects on the targets

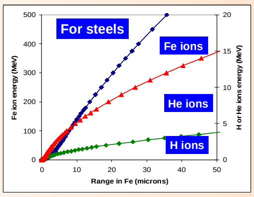
Tandem model accelerator with energy range around 18 MeV for He and 6-10 MeV for H



IBA Cyclone 70 MeV, for Fe, w, Si , C ions acceleration

		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/cm³)	26.6	Fe	385	H	2.5	He	10
W (19.3 g/cm³)	10.1	W	373	H	1.6	He	6
C (2.3 g/cm³)	148	C	96	H	4.5	He	18
SiO_2 (2.2 g/cm³)	175	Si	337	H	4.6	He	18
SiC (3.2 g/cm³)	122.4	Si	337	H	4.6	He	18
SiC (3.2 g/cm³)	122.4	Si	337	D	6.0	He	18

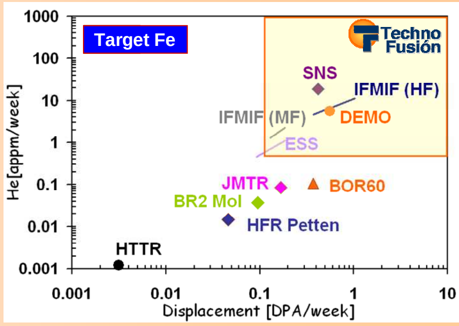
Ion energies that will be used, assuming a He energy ≤ 12 MeV (Tandem at 6 MV terminal voltage and charge states of -1 and +2)



Range in Fe by Fe, He and H ion energy under homogenous irradiation

	Ion Currents (pnA)
C	500 – 1000
Si	200
O	200
Fe	25
W	3

Target intensity for each ion species in the cyclotron

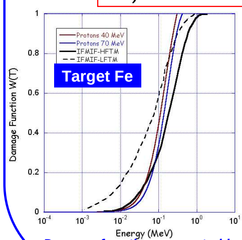


Comparison of results from different facilities (particle accelerators, fission facilities and future fusion facilities), during homogeneous irradiation of Fe and He ions beam with a maximum energy of 300 and 10 MeV respectively, using different intensities.

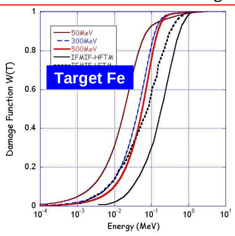
The **effects of neutrons on the materials** involve two physical phenomena:

i) **Displacement** of atoms from their lattice sites creating point defects

ii) Nuclear **transmutation reactions** contributing to the rising of impurities (**He, H, etc**) inside the materials



Damage function generated by protons of 40 y 70 MeV



Damage function generated by Fe ions of 50, 300 and 500 MeV

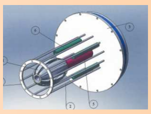
Two approaches are proposed, depending on the damage-production processes, and the generation of H and He:

I. Irradiation with ions of the same species, alongside with **a simultaneous double implantation with light ions** (H and He). This triple irradiation solution is expected to generate the same amount of defects and the same amount of light ions (via H and He implantation) to be reached under neutron irradiation in the fusion facilities

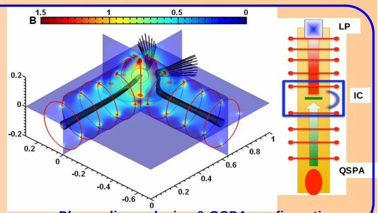
II. Irradiation with 40 and 70 MeV protons to generate damage and light elements in a similar way to those generated by neutrons in fusion reactors. On the other hand, **H^+ are able to produce H and He** in the material by nuclear transmutations, in a similar fashion as those found by neutron irradiation

PLASMA-WALL AREA

- **Plasma Linear Device in consonance with a perpendicular quasi-stationary plasma accelerator (QSPA)** for reproducing stationary plasmas and transient events (reactor-like conditions)
- **H, D, He, Ar Plasmas**, Magnetic Field of 1 T
- Fluencies of 10^{24} s^{-1} at relevant impact energies (<10 sec. of 10 eV)
- Simultaneous exposure to transient loads in a range of 0.1-40 MJ m^{-2}. Maximum Power Density < 100 GWm^{-2} (0.5 ms)
- Testing of **reactor relevant PFC materials** to plasma exposure in reactor-like conditions
- **Fuel retention** and exploration of combined effects (Plasma + ion irradiation)
- **ELMs Simulation, dust generation**, etc



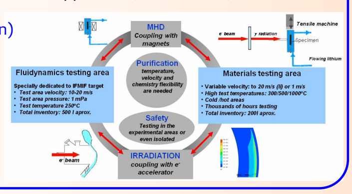
QSPA source design



Plasma linear device & QSPA configurations

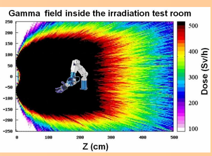
LIQUID METALS AREA

- A **Medium-size flexible liquid metal (Li) loop** for fusion application, VL=4-20 m/s, T°=250-500 °C
- **Free surface experiments** together with a e^- accelerator @ 10 MeV (IFMIF Blanket simulation)
- **Corrosion studies** also under gamma irradiation
- **MHD and B** effect on the Li liquid
- **Purification experiment** and monitoring
- **Permeation studies**, including coatings developments
- Liquid metal **diagnostic development**



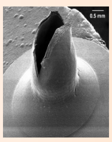
REMOTE HANDLING AREA

- Devoted to the development and assessment of **new remote handling fusion techniques**
- Facility for **prototype manipulation** (*Port Plug Diagnostic* (PPD) and Test Blanket Modules (TBM) of ITER and Modules of irradiation of IFMIF)
- **Irradiation Test Room**, coupled to e^- accelerator (e^- @ 10 MeV gammas @ 100-500 sv/h) for validation, certification and characterization of RH tools and machines in an uniform ionizing field equivalent to ITER-DEMO and future fusion reactors



CHARACTERIZATION TECHNIQUES AREA

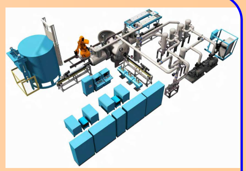
- Development of in-beam and after radiation techniques to analyze physical and mechanical properties (tension, nanoindentation, creep, fatigue, resistivity, luminescence, absorption, thermal conductivity, diffusion,…)
- IBA, SIMS, APT, FIB, TEM+EELS, …
- **To characterize the manufactured and modified materials** (Compositional, microstructural and physical)



TEM+EELS image technique

PRODUCTION & PROCESS MATERIALS AREA

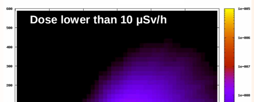
- A facility to bridge the new material production gap between research groups and companies
- Semi-industrial manufacturing and creation of prototypes
- Production and manufacture capability of priority materials (ODS steels, nano-structured steels, W alloys, ceramics, …)
- Advance materials processing (mechanical allowing, VIM, HIP, SPS, ..) and manufacturing techniques (welding, joining, shaping techniques)



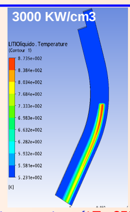
Vacuum Plasma Spray Facility

COMPUTER SIMULATION AREA

- Computational simulation of the components at the TechnoFusión facilities and those at ITER, DEMO and IFMIF (neutronics, fluidodynamics, tritium, mechanical behaviour…), taking into account radiation effects



Spatial distribution of dose rates. Implantation of H and He in Fe and C samples.



Rise in temperature (ΔT : 350ºC) under irradiation of 1 MeV in the Free Surface Experiment

OUTLINE

- TechnoFusión will include a set of facilities, in seven experimental and technological areas, to provide new tools for the development of nuclear fusion technologies
- **Encouraged by the European Facility Review Panel**
- **User facility located in Madrid, Spain**
- A new relevant multi-**characterization facility, with a triple ion beam for irradiation of materials**, able to screen radiation damage phenomena relevant for ITER, IFMIF and DEMO environments
- Triple beam irradiation and proton irradiation are good candidates to simulate the damage on materials by neutrons in a nuclear fusion facility
- The facility will also be used to analyze the performance of such materials and to design new ones (test and development of materials for fusion reactors)