Research for an Integral Study of Inertial Fusion reactor:

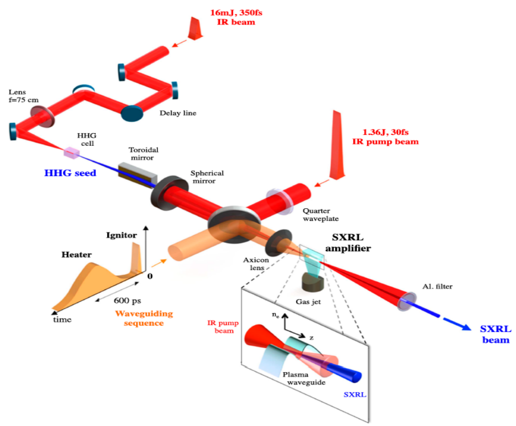
J. Manuel Perlado
President-elect
Instituto de Fusión Nuclear "Guillermo-Velarde"
Universidad Politécnica de Madrid

Instituto Fusión Nuclear “Guillermo Velarde”
Areas

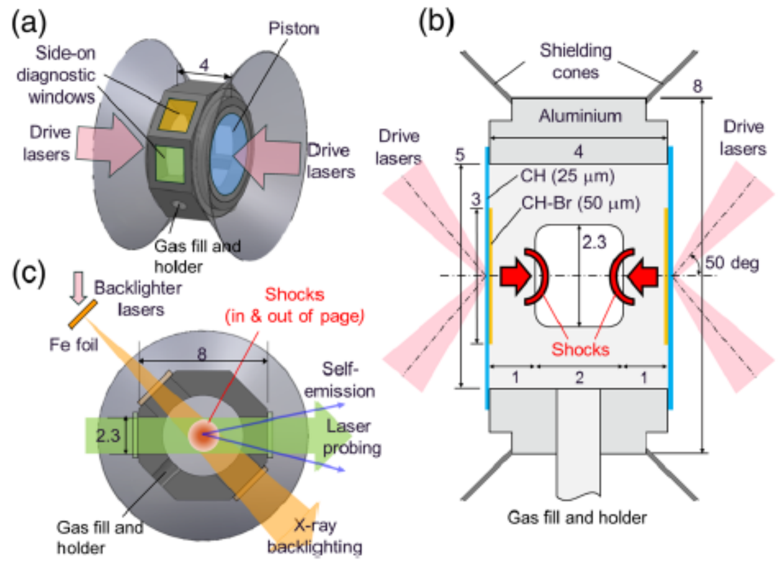
- High- Energy Density physics:
  - X-ray, XUV sources, Radiative Shocks, and IFE targets design.
- Atomic Physics for High Density Plasmas
- ***Materials under irradiation and extreme conditions (fusion-fission-transmutation) in Nuclear Fusion:***
  - ***Plasma Facing Components/First Wall materials***
  - ***Target materials: EOS of Hydrogen***
  - ***Optics***
- ***Neutronics: Activation, Tritium, Heating, Structural Materials***
- Radiation Sources:
  - Neutron, Ions:
    - European Spallation Source (ESS-Bilbao)
    - Laser-based ion and neutron sources
- Laboratories for Materials Implantation, Characterization and Permeation

Two items in High Energy Density Physics

- Applications to 3D Image and Diagnosis
  (*Plasma Phys. Control. Fusion 60 (2018) 014030*)
  - Compact Amplifiers design for X-ray lasers based in plasmas.
  - Interaction of High Intensity X-ray Lasers with matter (Free electrons Lasers)
    - Laboratoire d'Optique Appliquée (ENSTA, Paris), CNRS, CEA, LULI
    - Group of lasers and Plasmas (GOLP, Lisboa)



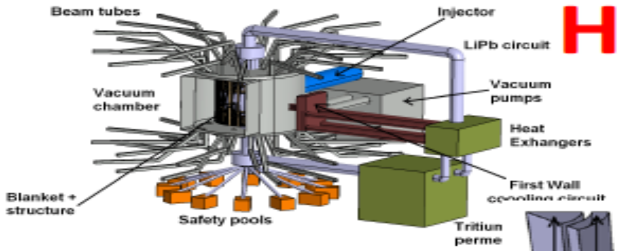
Radiative Shocks formation and Counterpropagating
(*PRL 119, 055011 (2017) Experiments in ORION*)

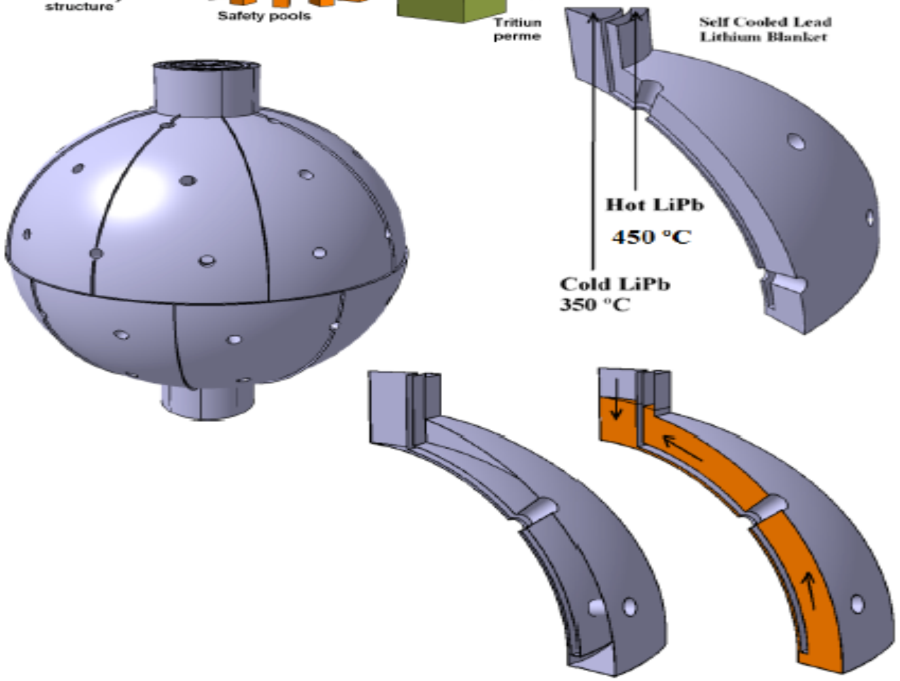


Pathway proposed in HiPER project

	HiPER 4a	HiPER 4b (Power plant)	
	EXPERIMENTAL	PROTOTYPE	DEMO
Description	Bunch mode	Relaxed operation	Pre-commercial power plant
Operation	Bunches of 100 shots, max. 5 DT explosions	Continuous (24/7)	Continuous (24/7)
Yield (MJ)	<20	>20	>100
Rep. rate (Hz)	1-10	1-10	10-20
Power (GWt)	-	<0.5	1-3
T cycle	No	Yes	Yes
Blanket	No	Yes	Yes

Using experience in designing Dry Chamber for HiPER Direct Drive Project





HiPER European Project

HiPER

- ✓8 years running
- ✓Stopped as European funded 2014

SHOCK IGNITION

DRY WALL

✓Advanced Progress in Materials and Reactor design research under Spanish National Programs with significant Spin-off in other areas of science

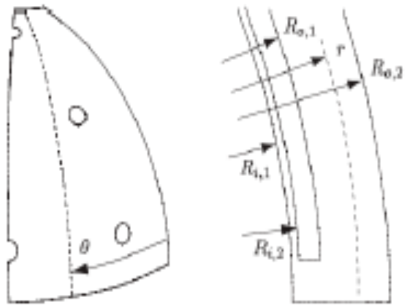
IFN-GV

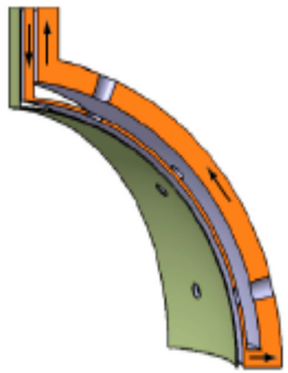
INDUSTRIALES ETSII | UPM

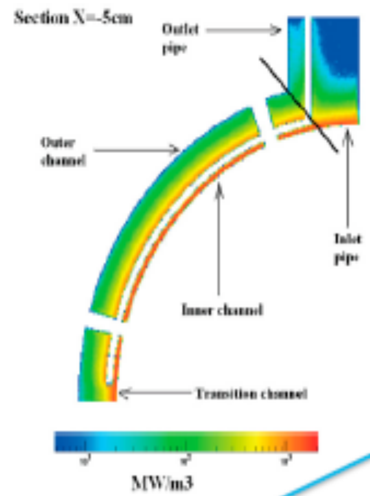
Using experience in designing Dry Chamber for HiPER European Direct Drive Project

IFN-GV

45° section of blanket module







$R_{i,1}$ = 6.51 m, $R_{i,2}$ = 6.59 m
$R_{o,1}$ = 6.81 m, $R_{o,2}$ = 7.51 m

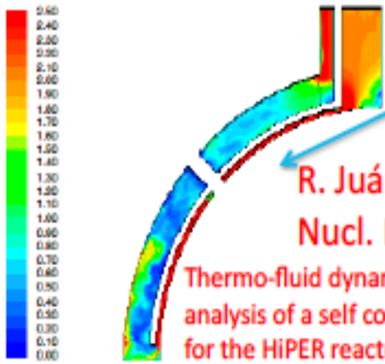
Parallel latitudes: 69.77° (4 holes), 42.97° (8 holes) and 15.05° (12 holes)

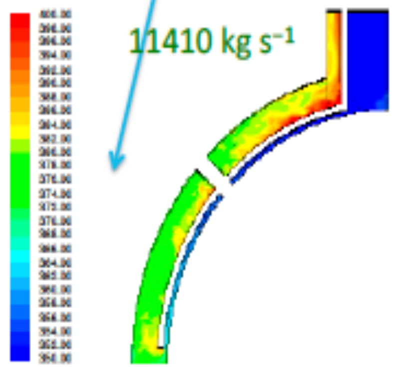
mass flow rate of Pb– 15.7Li:

5993, 8557 and 11410 kg s^{-1}

Velocity magnitude contours (m.s^{-1}) and Temperature contours °C at $\theta^*=\theta/45°=0,5$

11410 kg s^{-1}





R. Juárez et al 2015
Nucl. Fusion 55 093003,
Thermo-fluid dynamics and corrosion analysis of a self cooled lead lithium blanket for the HiPER reactor

Last 5 years: Emphasis in Research areas

Plasma Facing Materials: NANOSTRUCTURES based in W, HOLLOW NANOSpheres.

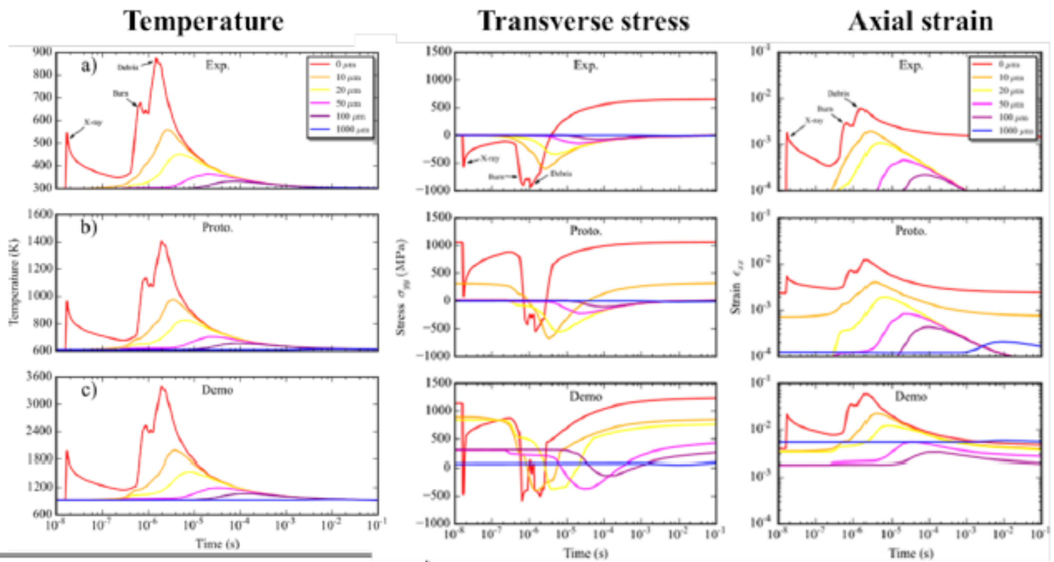
CORROSION: COATINGS based in SiC and Nanomaterials

OPTICAL MATERIALS:
- NANOPLASMONIC-Nanoparticles
- Thermal Shielding for Radiation Heating

NEUTRONICS: Tritium Breeding Dynamic Control and Tools for detailed 3D calculations including uncertainties

Time dependent *Thermo-mechanical Loads* and *Coarse Grained W*

Appropriate chamber geometry, radiation mitigation strategies, materials engineering and a reduced target yield may lead to an acceptable thermo-mechanical response. But, atomistic effects cannot be avoided, and *for conditions of Reactor coarse grained Tungsten is not acceptable*



HiPER			
	Experimental	Prototype	Demo
Frequency	Few shots per bunch	1 Hz	10 Hz
Shot Energy (MJ)	20	50	154
Inner chamber radius (m)	5	6.5	6.5
Operation time limit based on thermomechanical considerations (hours)	No	14×10^3 (580 days)	28
Operation time limit based on synergistic effects (thermal loads + He irradiation)	~1×10^3shots	minutes	seconds

PULSED THERMAL LOADS and COARSE GRAINED W LIMITATIONS

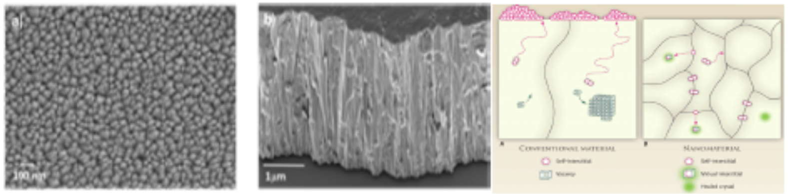
Gonzalez-Arrabal, R., Rivera, A. and Perlado, J. M., In Matter and Radiation at Extremes, volume 5, 2020

D. Garoz *et al*. Nucl. Fusion **56** (2016) 126014

Columnar Nano-W ***research as PFM***

NEW APPROACHES: NANOSTRUCTURED W

Nanostructures ↔ more radiation resistance

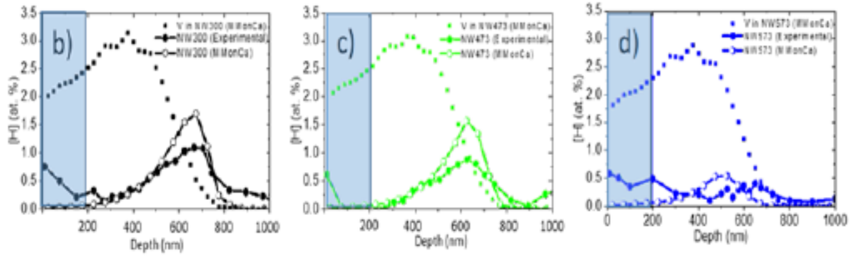


R. Gonzalez-Arrabal *et al.* JNM453 (2014) 287–295

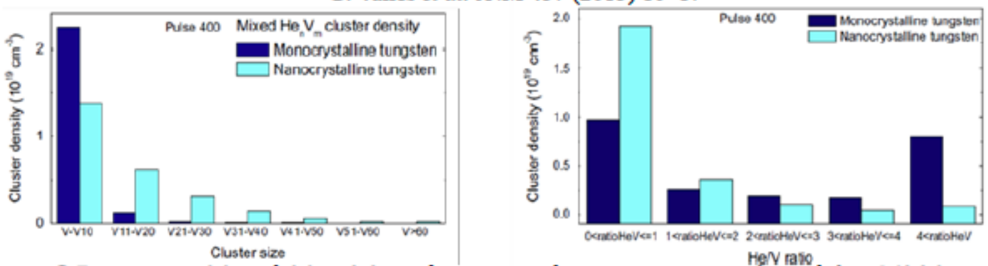
- **He irradiation**

G. Valles et al., JNM, volume 490, 2017.

- **H irradiation**



G. Valles *et al.* JNM 457 (2015) 80–87



- GBs trap He / He_nV_m clusters less pressurized in NW

M. Panizo-Laiz *et al.* Nucl. Fusion 59 (2019) 086055

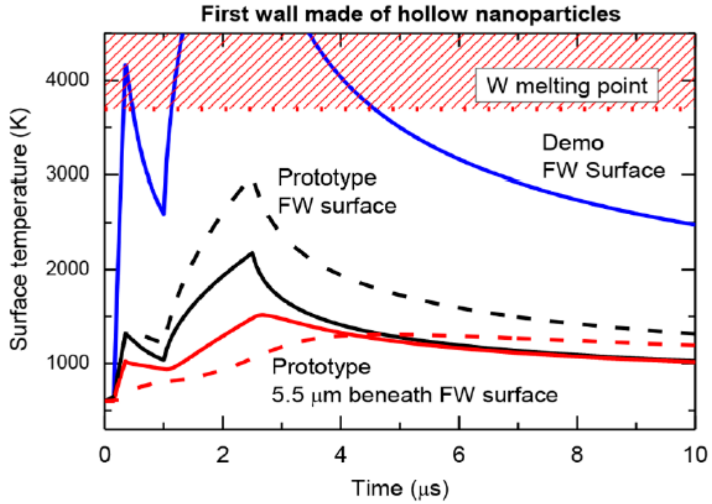
G. Valles *et al.* Acta Materialia 122 (2017) 277-286

- GBs diffusion channels for H
- H_nV_m clusters less pressurized in NW

NW favours the He and H retention in low populated vacancies, it may shift the fluence threshold for blistering to happen to higher values.

Gonzalez-Arrabal, R., Rivera, A. and Perlado, J. M., In Matter and Radiation at Extremes, volume 5, 2020

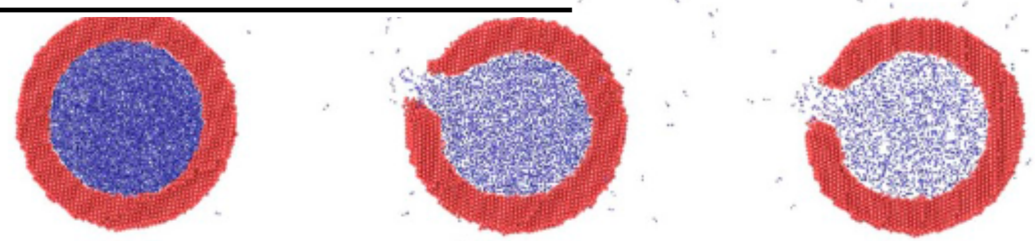
First Wall structure: ***HOLLOW NANOPARTICLES***



P. Díaz-Rodríguez et al.,Nucl. Fusion 60 (2020) 096017

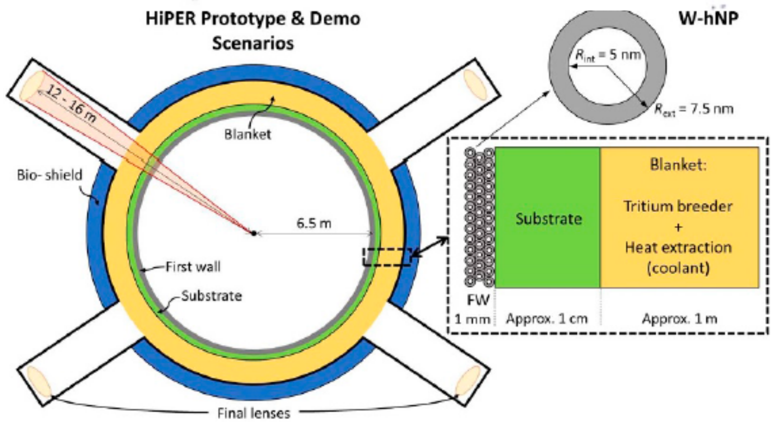
Temperature (K)	Number of He atoms in the cavity prior to rupture	Inner pressure (GPa)
300	52 100	10.5
1000	48 900	7.5
2000	37 500	6.7
3000	32 000	5.5

The W-hNP is able to resist very high internal pressures; however, rupture is produced at certain pressure depending on the temperature.



Temperature of a FW made of hollow NPs as a function of time after target explosion (t = 0) for target yields of 154 MJ (blue) and 50 MJ (rest), Demo and Prototype scenarios, respectively.In the Prototype scenario, the temperature at the surface (black) and at a depth of 5.5 μm beneath the surface (red) is plotted.

J.C. Castro-Palacio et al., J. Phys. Chem. Lett. 2020, 11, 13, 5108–5114



CORROSION by ***Liquid Metals: Coatings***

Coating development based in SiC

Challenge: development of corrosion resistant coatings

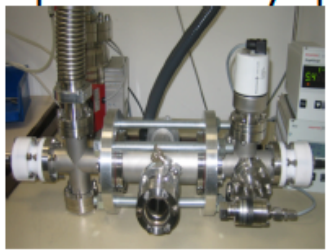
- ODS-steel and others in LM

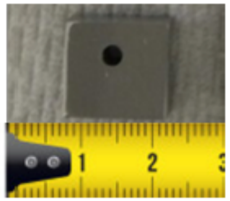
	Li	Pb–17 Li
F/M steel	550–600°C	450°C
V alloy	650–700°C	~650°C
Nb alloy	~1300°C	>600°C (>1000°C in Pb)
Ta alloy	>1370°C	>600°C (~1000°C in Pb)
Mo	>1370°C	>600°C
W	>1370°C	>600°C
SiC	<550°C	>800°C

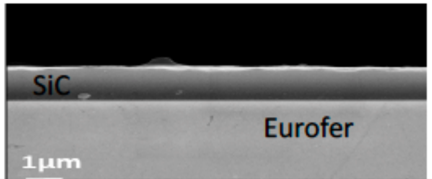
S. J. Zinkle, Fus. Eng. and Des. 51-52, (2000) 55-71

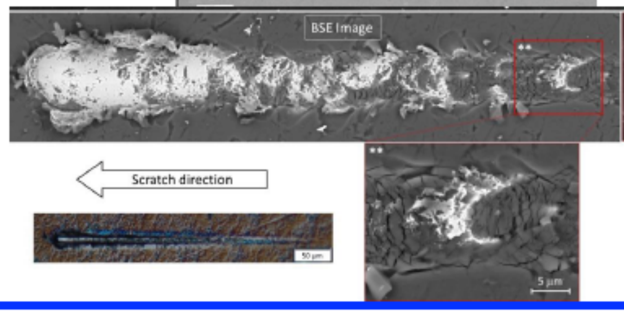
We have optimized the sputtering procedure to obtain coating well adhered to the ODS steel (Eurofer).

Development of a set up to cover by sputtering the inner walls of pipes.







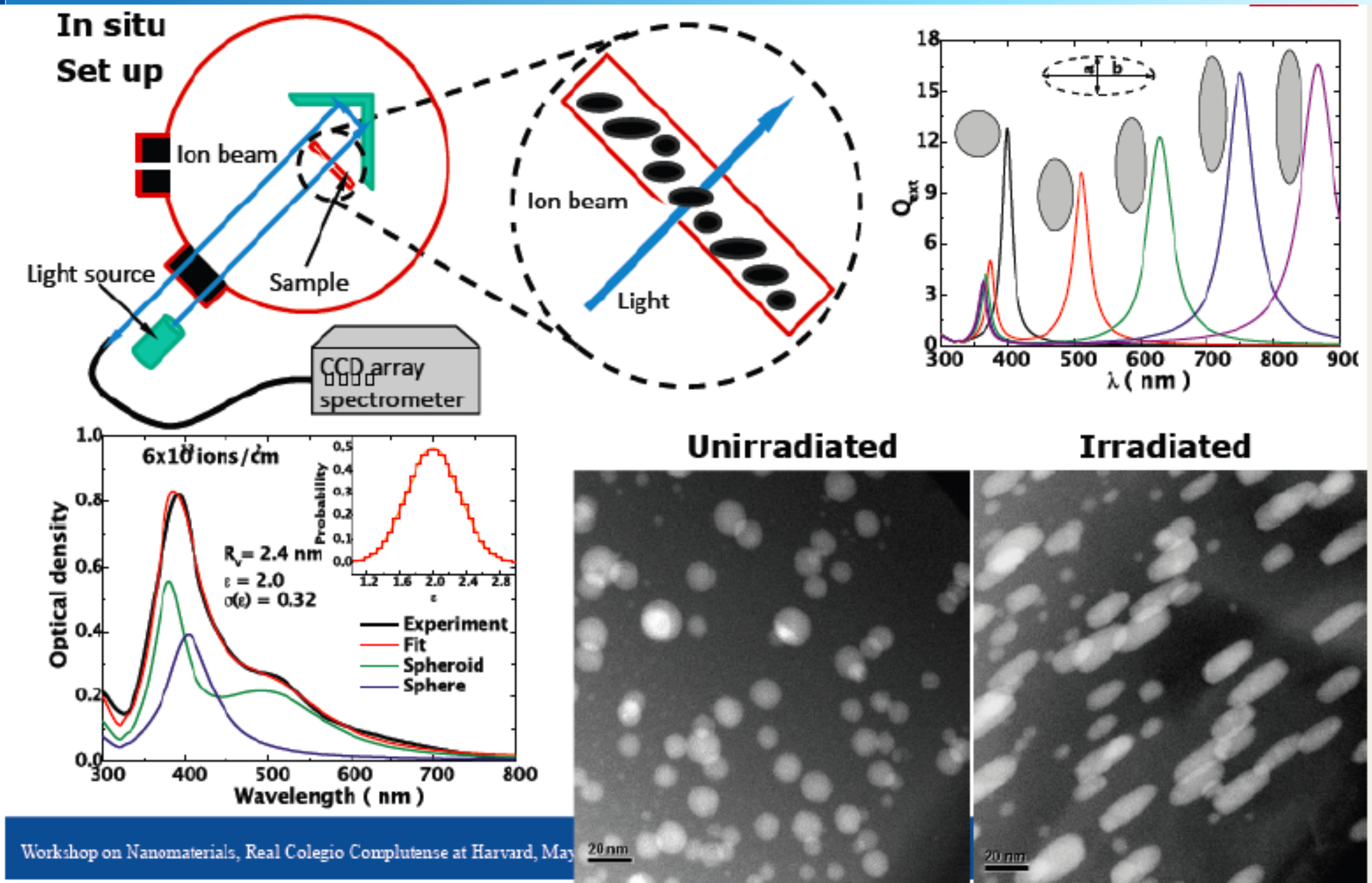


$L_C = 194.5 \pm 5.8$ mN

T. Hernandez *et al. Nuclear Materials and Energy 25 (2020) 100795*

INDUSTRIALES ETSII | UPM

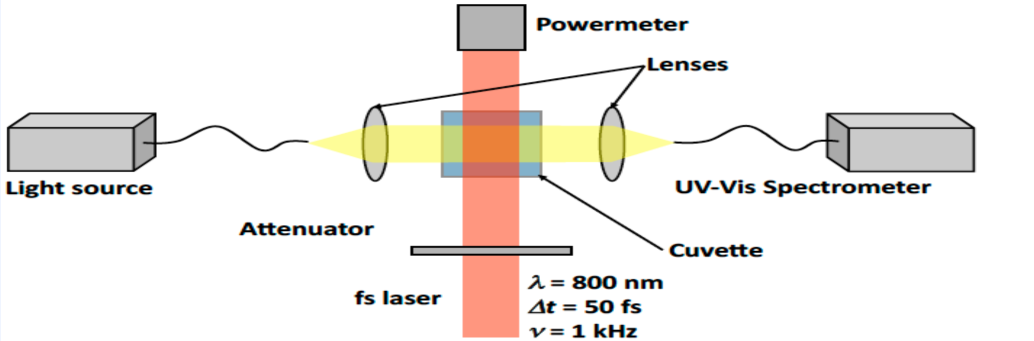
OPTICAL RESPONSES: *PLASMONIC NANOPARTICLES*



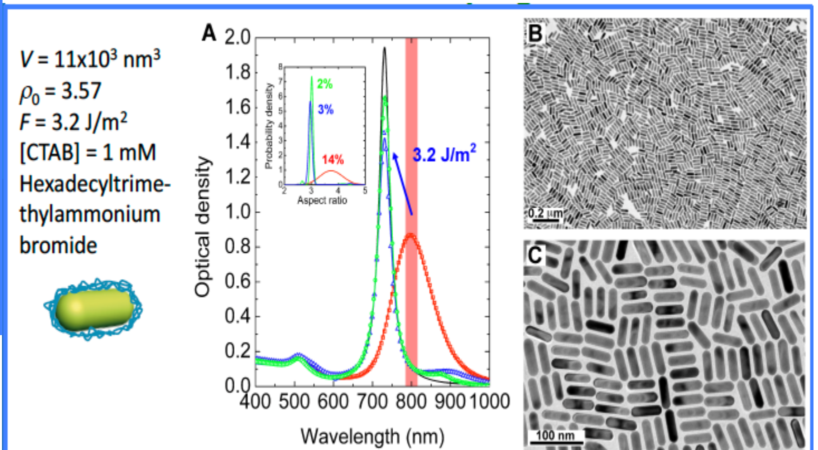
Peña-Rodríguez, O., et al., in Scientific Reports, volume 7, 2017.

IFN-GV

Optical responses: ***Laser Gold Nanorods***



G. González-Rubio, P. Díaz Nuñez, O. Peña, A. Rivera, A. Prada, et al., Femtosecond laser reshaping yields gold nanorods with ultranarrow surface plasmon resonances, Science 358 (2017) 640–644

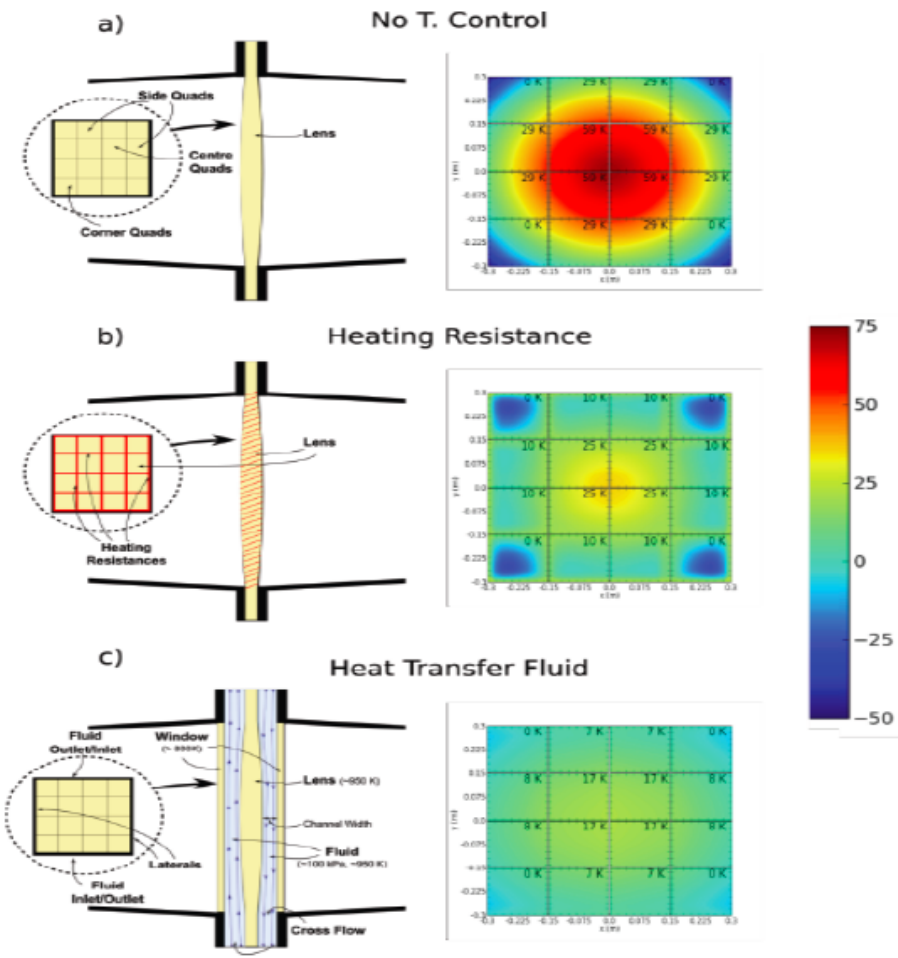


G. González-Rubio, P. Díaz Nuñez, O. Peña, A. Rivera, A. Prada, et al., Femtosecond laser reshaping yields gold nanorods with ultranarrow surface plasmon resonances, Science 358 (2017) 640–644

G. Gonzalez-Rubio et al., Science 358 (2017) 640-648;
Peña-Rodríguez, Ovidio, et ., in Scientific Reports, volume 10, 2020.

- Irradiation of gold nanorod colloids with a fs laser yields colloids with ultra-narrow localized surface plasmon resonance (LSPR)
  - Gentle multi-shot reduction of the aspect ratio
  - Rod shape and volume are barely affected
- Successful reshaping requires a delicate balance
  - Irradiation fluence (i.e., **energy deposition**)
  - Surface density of the surfactant (i.e., **energy release**)

Optical Systems: ***Temperature mitigation and Aberrations***

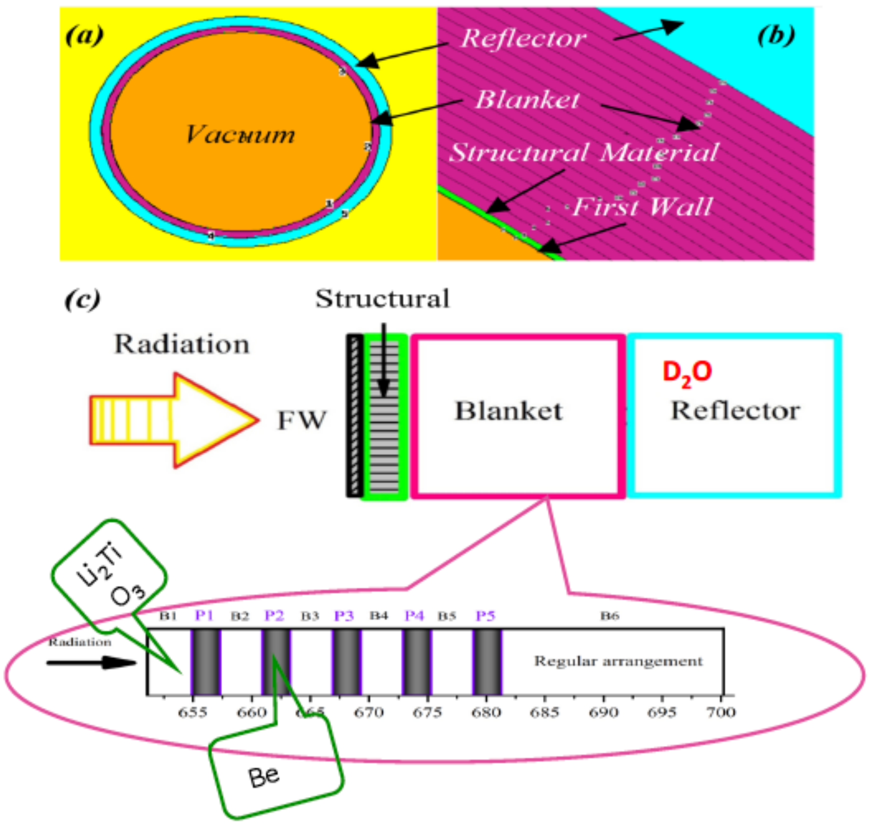


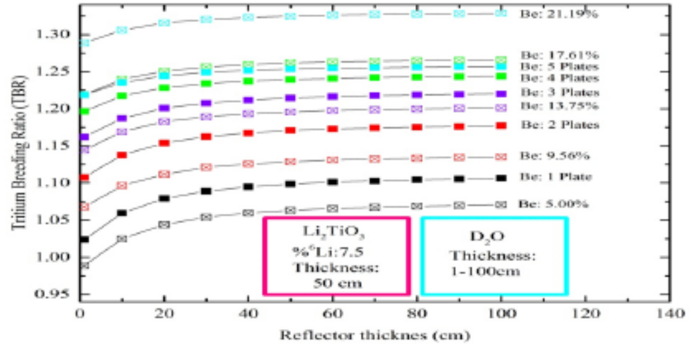
Engineering Proposal

Solution for Heating of Final Optics by Radiation and Ions.

Tritium Breeding ***Dynamic Control***

A. Fierro et al., Fusion Engineering and Design, volume 155, 2020



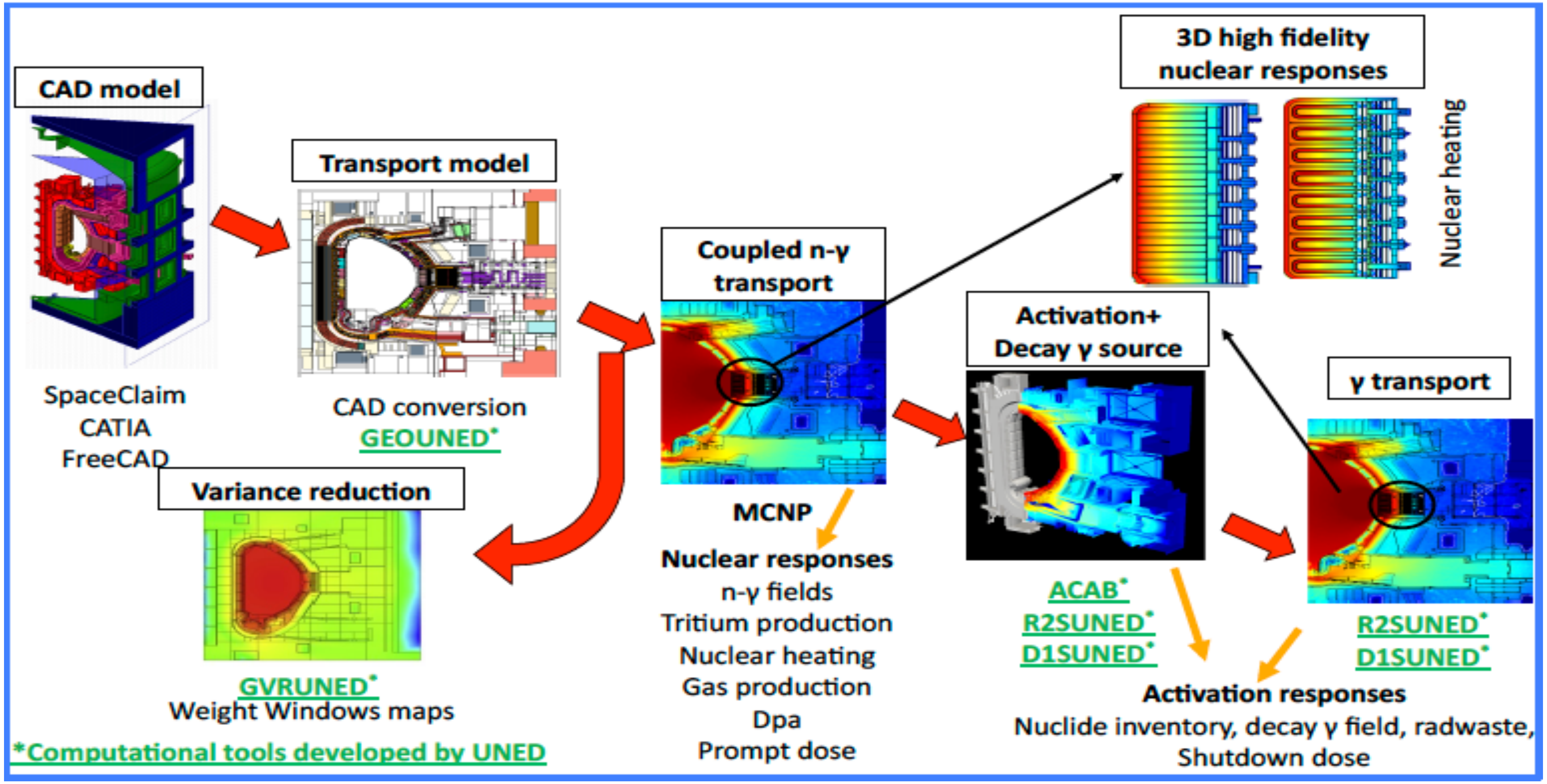


An operational window shows that it is possible to easily modify the TBR from 1.0 to 1.1 during operation.

This overcomes design uncertainties and assures tritium supply with a low tritium inventory.

Room for many other designs based on this concept

Tools for 3D detailed ***neutronics calculations***



Instituto Fusión Nuclear "Guillermo Velarde"

P. Velarde (Director), O. Cabellos, M. Cotelo, P. Díaz-Núñez, P. Díaz-Rodríguez, E. del Río, I. Fernandez[1], D. Garoz[2], R. Gonzalez-Arrabal, J. Kohanoff, F. Ogando[3], E. Oliva, M. Panizo-Laiz, O. Peña-Rodríguez, A. Rivera, J. A. Santiago[1], J. Sanz[3], P.. Sauvan[3], F. Sordo[4], E. Vázquez

[1]Nano4Energy
[2]IMDEA Materials
[3]UNED
[4]ESS-Bilbao

Contributors to this presentation

IFN-GV