The Liquid Metal Laboratory of TECHNOFUSIÓN Facility

A. Abánades, A. García, N. Casal, F. Sordo, A. Ibarra, J.M. Perlado, R. Vila, M.González

With the collaboration of IDOM

TECHNOFUSIÓN

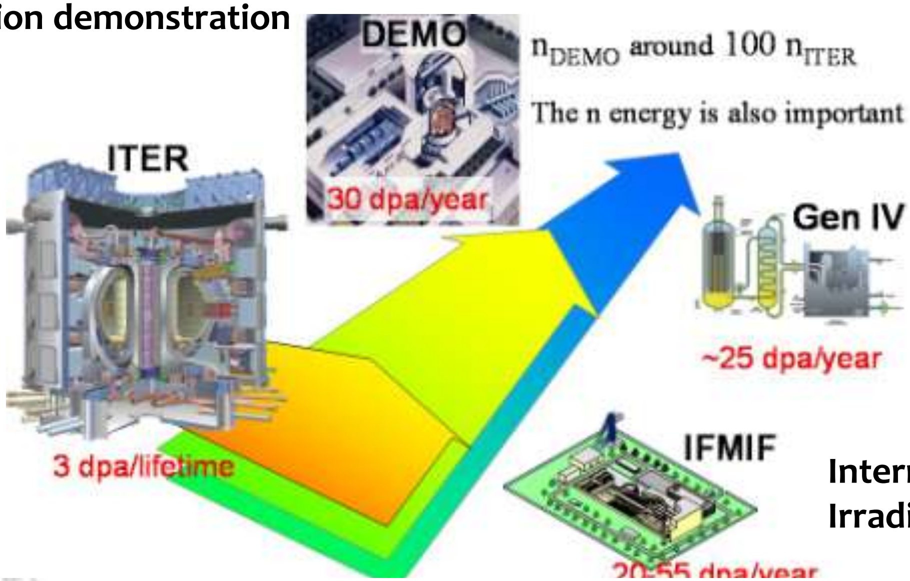
- **Nuclear fusion and the fusion European program**
- **Objectives of TECHNOFUSIÓN**

Nuclear fusion and the fusion European programme

- The development of thermonuclear fusion is one of the great technological world challenges
- The critical operating conditions of fusion reactors (high surface heat fluxes >50W/cm2, high neutron fluxes: material damage >70dpa, strong magnetic fields : ~5Tesla) demand research projects for the development of fusion materials
- The Regional Government of Madrid and the Spanish Science and Innovation Ministry plan 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 for the design and construction of ITER, IFMIF and DEMO, to develop a Fast Track for the Nuclear Fusion Energy.

Nuclear fusion demonstration reactor

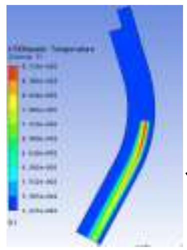
International Thermonuclear Experimental Reactor



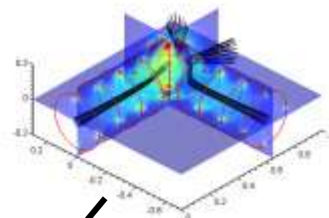
International Fusion Materials Irradiation Facility

Objectives of TECHNOFUSIÓN

Computational Simulation Laboratory
Computer simulation

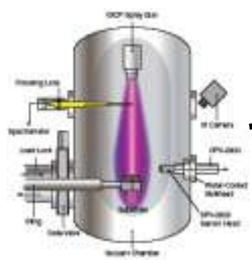


Irradiation methods Laboratory
Studies of the radiation effects on structural and functional materials using simultaneous ions and electron accelerators



Plasma/wall interaction Laboratory
Evaluation of plasma interactions with first wall materials

Materials Production and processing Laboratory
Development of advanced manufacturing technologies



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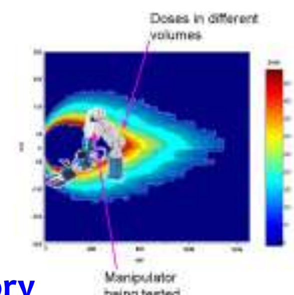
Liquid Metals Laboratory
Improvement of liquid metal technologies

Characterization Techniques Laboratory
Materials characterization



Remote Handling Laboratory
Tests of robotics and automation for Remote Handling (RH) including irradiation operation

The Liquid Metal Laboratory

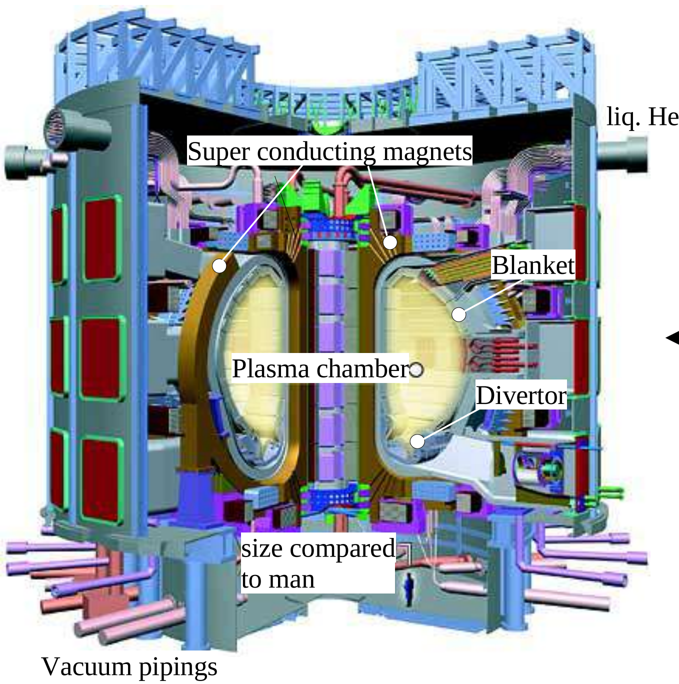
- Introduction
- Liquid lithium applications
    - Advanced fusion blankets
    - First wall, divertor and limiter of new concepts of fusion reactors
    - IFMIF
- International situation
- Liquid Lithium Laboratory at TECHNOFUSION
- Project development
- Preliminary loop definition
- Upgrade: Free surface experiments with electron beam irradiation
- Conclusions

Introduction

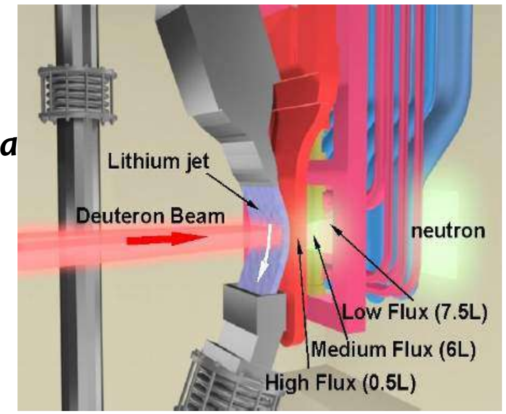
The liquid metal laboratory will consist of a modular liquid lithium loop for fusion applications.

Motivation: Lithium as one of the most relevant materials in fusion technology

Nuclear fusion reactors



Necessary coupled investiga



Materials technology

Liquid metals (Li included) as breeder material, first wall, divertors, limiters for fusion reactors

Advantages

-High thermal conductivity

-Practical immunity to irradiation damage

-Possibility to bring the breeder material outside the device for tritium extraction

-Relatively simple designs

Liquid lithium is used as target for the International Fusion Material Irradiation Facility (IFMIF).

Since d+Li reaction yields a neutron field which produces effects on materials similar to the expected ones in a fusion reactor

Liquid lithium applications: Fusion blankets

Blanket: Part of the reactor located just behind the first wall

In electricity generator fusion reactor employ the d+t reaction to have:

Breeding blankets function

Breeding capability (Tritium from Li)

Heat removal from the wall

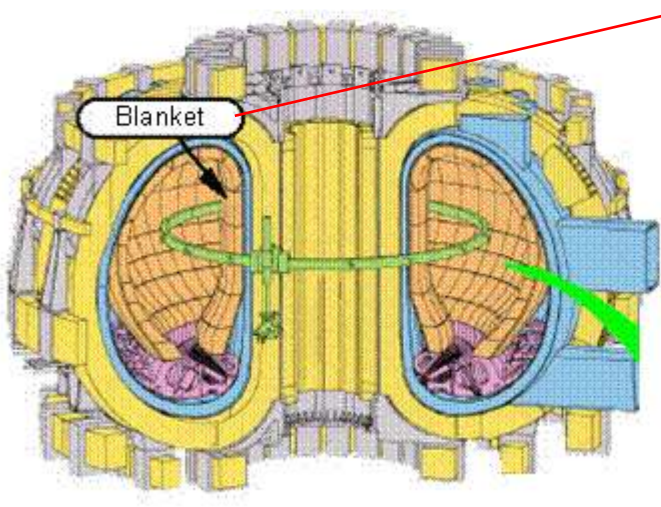
Shielding

Fusion conditions

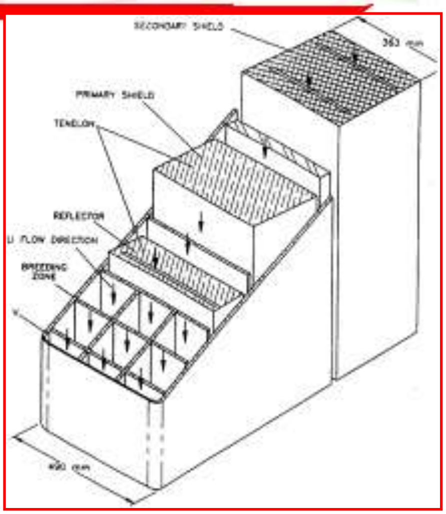
High surface heat fluxes >50W/cm2

High neutron fluxes (material damage >70dpa)

Strong magnetic fields (~5Tesla)



Fusion Device (tokamak type)

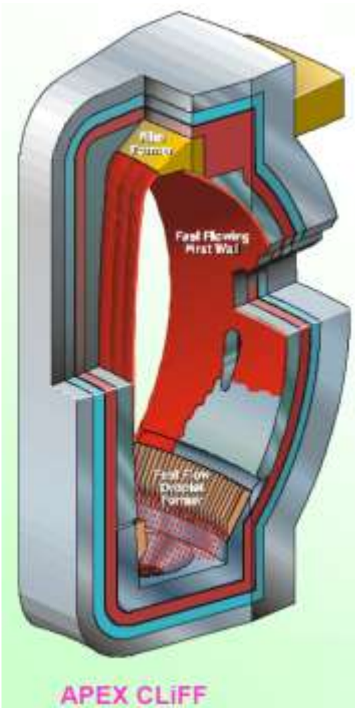


Example of self-cooled Li-V blanket design.

Main design problems and safety issues of liquid metal blankets:

- MHD effects: Pressure drop, flow partitioning in parallel channels and heat transfer reduction
- Corrosion of structural materials
- Tritium control
- Chemical reactions between liquid breeder, water and air

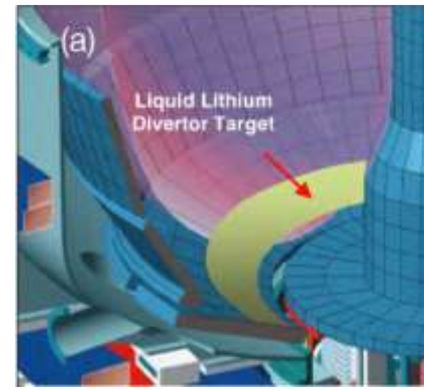
Liquid lithium applications: First wall, divertors and limiters of new concepts of nuclear fusion reactors



..in which liquid lithium will form the surface in direct contact with plasma

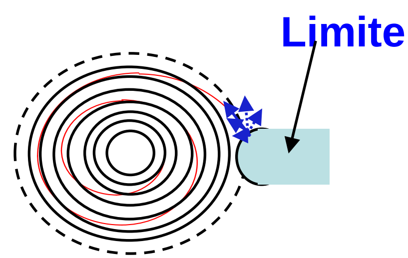
A very innovative concept that could bring some advantages for the long term:

- Plasma Stability and Confinement
- High Power Density Capability (which will eliminate thermal stress and erosion as limiting factors in the first wall and divertor)
- Reduced Radiation Damage in Structural Materials
- Potential for Higher Availability

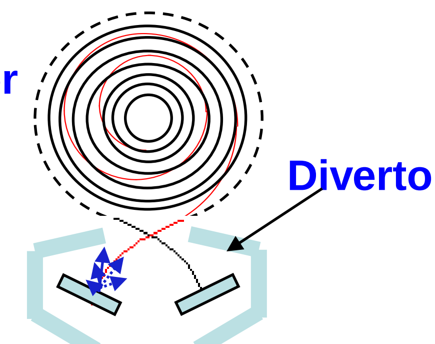


Great R&D Effort will be expected in the future

- Plasma-Liquid lithium wall interaction
- Fluid Mechanics and Thermodynamics
- Evaporation
- Free surface behaviour
- …



Limiter plasma configuration

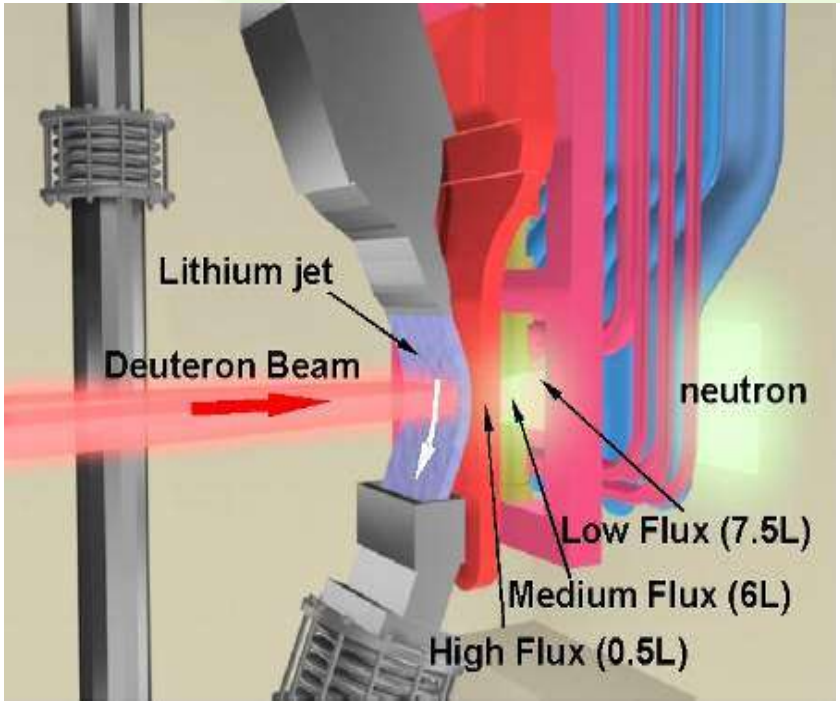


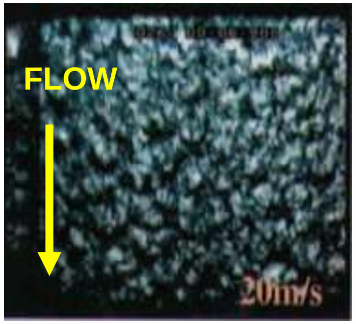
Divertor plasma configuration

Liquid lithium applications: IFMIF target

IFMIF consists of two linear accelerators, each one producing a beam of 125 mA of deuterons at 40 MeV.

Deuterons will impact in a target of liquid Lithium flowing at high velocity, in the range of 10-20 m/s. Nuclear reactions will produce a neutron flux which will be used for irradiation of specimens for further mechanical analysis of interest in the fusion field.





Stability requirement for the jet flow : Fluctuation of the target free surface not exceeding ± 1 mm

Main R&D necessities about the Li-target:

- Investigation of the stability of the free surface flow
- Estimation of temperature distribution in the lithium and evaporation
- Investigation of the interaction between Li flow and back wall structure
- Out of design scenarios analysis
- Instrumentation
- Purification system

Liquid lithium applications: IFMIF target

➢ Other phenomena that appear in experiments, but are not yet enough assessed:

- *perturbances induced by tray lateral walls (do affect to foot print?)*

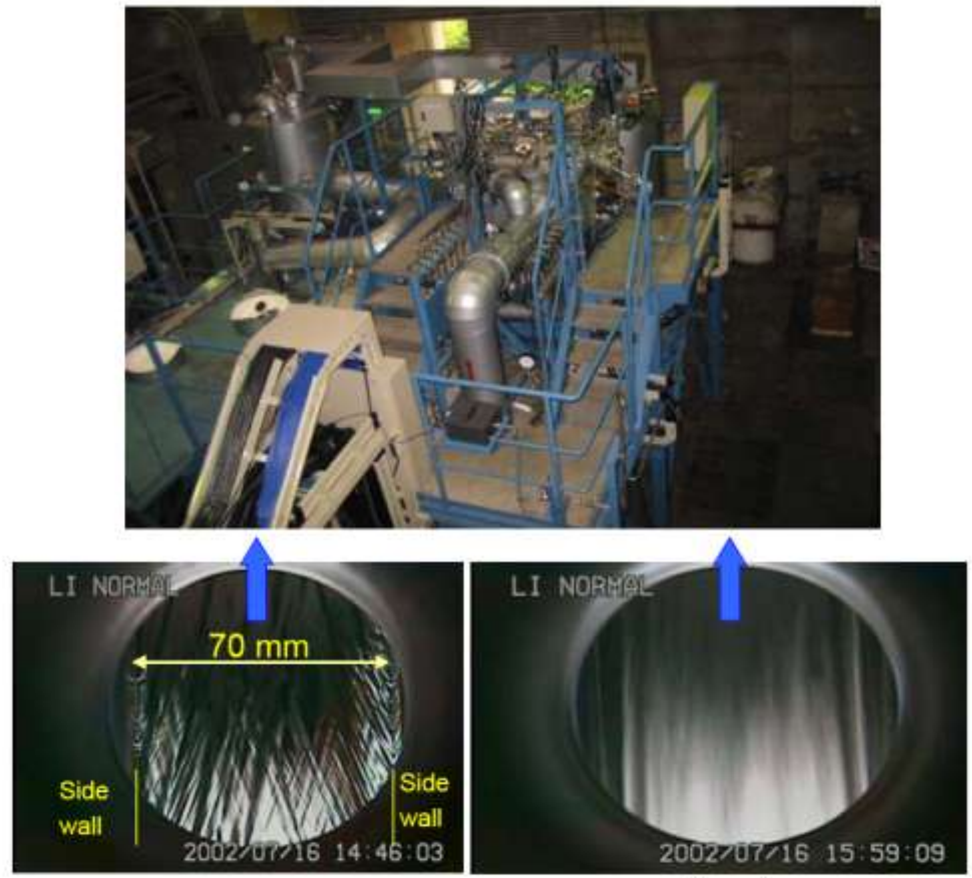
- *steady operation of the loop in vacuum conditions (cavitation noises, foam in the quench tank… detected by IPPE)*

- *flow stability affected by*

    - *geometrical design issues (needed accuracy of different components positioning, nozzle exit shape, lateral walls, backwalll curvature…)*
    - *dirtyness / erosion in the nozzle exit*

- *deposition / distribution of lithium liquid and gas in the chamber (evaporation, splashing, etc.) and interaction with beam*
- *…*

Osaka University Lithium Loop



2.2 m/s   13 m/s

International situation

In order to deal with many of the exposed problems, there are some reference facilities in the world. Nevertheless:

- There is lack of facilities related with the lithium technology, specially in Europe. Furthermore, some of the experiments are performed with relatively low temperature (350°C, LIFUS-3).
- There is no facility that be able to simulate a power deposition into the liquid lithium bulk of IFMIF.
- The present status of liquid metals R&D and their increasing technological applications makes necessary the creation of new scientific and technological infrastructures

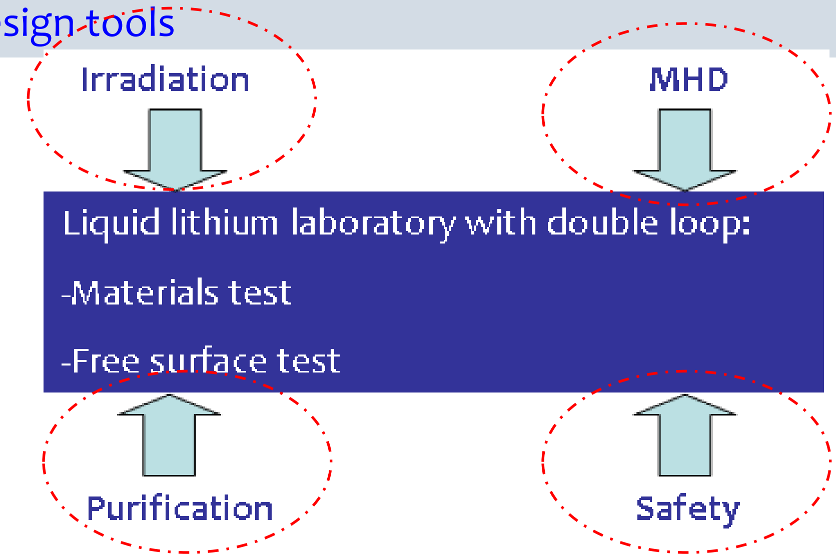
Pure lithium	
JAPAN	Osaka University
USA	Argonne National Laboratory Plasma Physics Laboratory University of California University of Illinois Oak Ridge National Laboratory
RUSSIA	Efremov Institute (MHD)
ITALY	ENEA (LIFUS-3)
Pb17L	
ITALY	ENEA (LIFUS-2, LIFUS-5, TRIEX, RELA III, LEDI, LTF-M)
FRANCE	CEA (MELODIE, PABLITO, DIADEMO)
GERMANY	FZK (PICOLO, MEKKA)
CHEZK REPUBLC	IPP, LATVIA, IPUL

Liquid Lithium Laboratory at TECHNOFUSION

A lithium loop has been proposed, including new capabilities allowing the development of experiments such as the free surface plus heat deposition.

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

- Free surface behaviour (including electrons from one accelerator and vacuum conditions)
- Corrosion (including electrons from the electron accelerator)
- MHD effects
- Purification
- Safety
- Validation of design tools



Some of these experiments will require the interaction with other Technofusion facilities

Project development

The project development is foreseen by steps:

In the **first step** the basic infrastructure of the lithium loop will be developed. It will allow the performance of experiments related to **materials**: corrosion tests, in situ mechanical properties tests, etc. and **free surface** experiments

The **second step** will address the required upgrading for **free-surface** experiments with heat deposition. Also the irradiation of the materials test section will be taken into account at this stage.

This free surface tests are mainly oriented to IFMIF and, for that reason, the following technical specifications are proposed:

- **Operational temperature: 250°C**
- **Vacuum condition: 1mPa**
- **Lithium velocity: Up to 20 m/s**

On the other hand, the objective regarding materials testing is to achieve higher operational temperatures **up to 700°C or even 1000°C.**

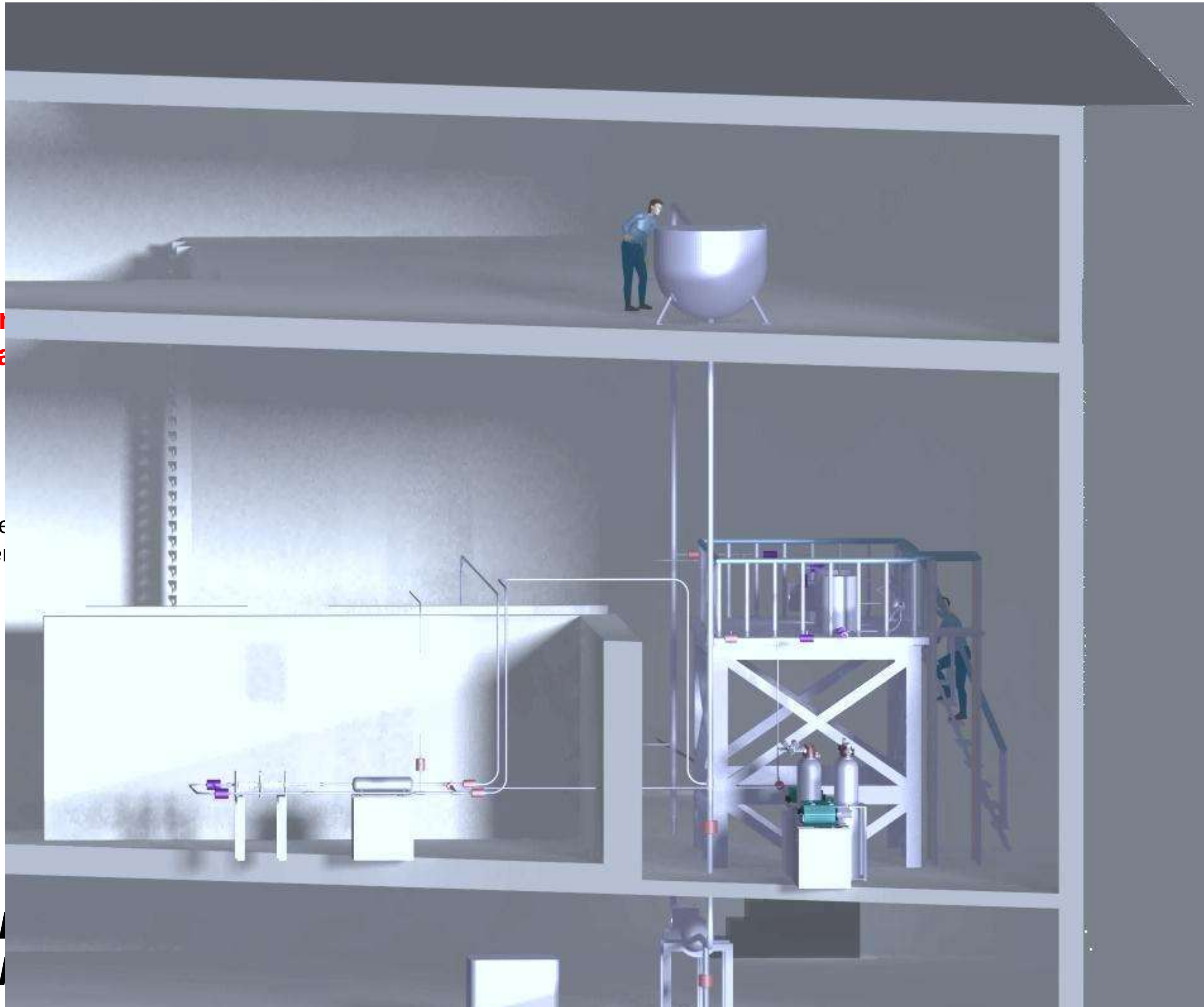
Finally, in other stage, the incorporation of other experiments like MHD studies will be developed

Preliminary loop definition

r Free

Experi
materia

He
re



UPGRADE: Free surface experiments with electron beam irradiation

IDEA:

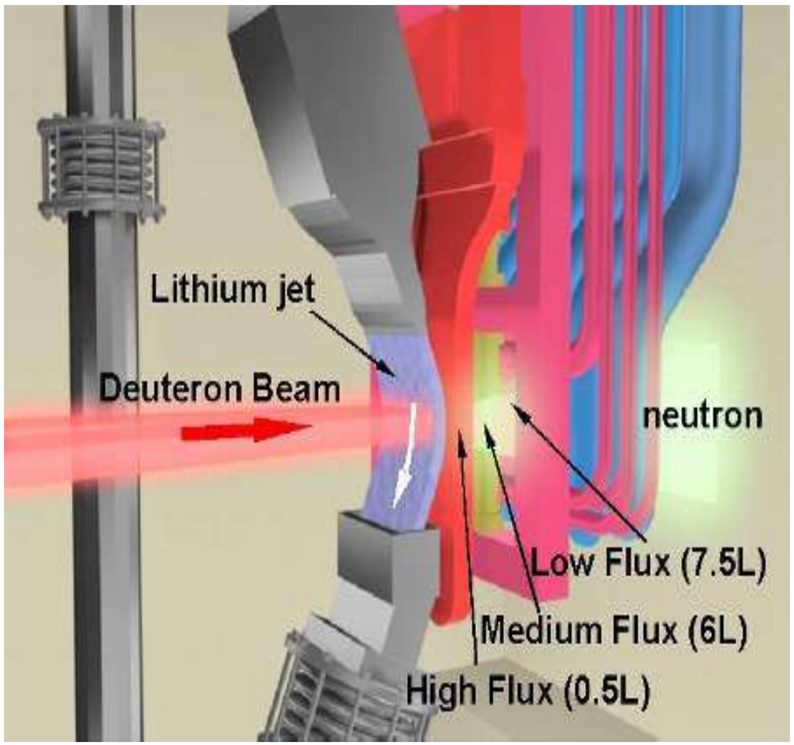
Impossible reproduction of 10MW without 40 MeV deuterons in a facility without neutrons...

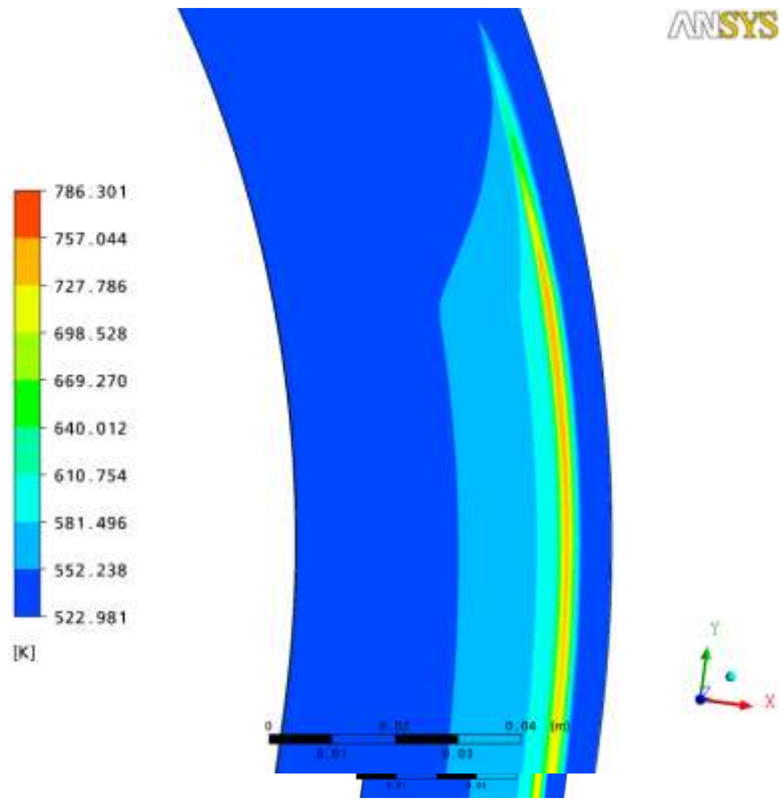
Reproduction of relevant power densities or max. temperatures in some local point

IFMIF target will receive 10 MW which means:

Maximum power deposition at IFMIF target

- **2 cm from the free surface (80% of the total depth)**





¿It is possible to obtain a relevant power deposition by electron beam (no activation problems)?

Maximum temperature: 401°C

UPGRADE: Free surface experiments with electron beam irradiation

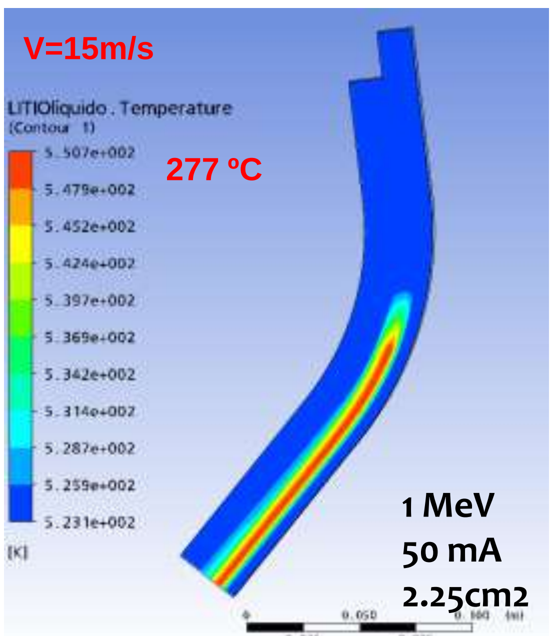
Taking advantages of the Irradiation Methods Laboratory of Technofusion, one of their accelerators will be also used for this purpose:

Electrons of 1Mev with intensity up to **70mA**

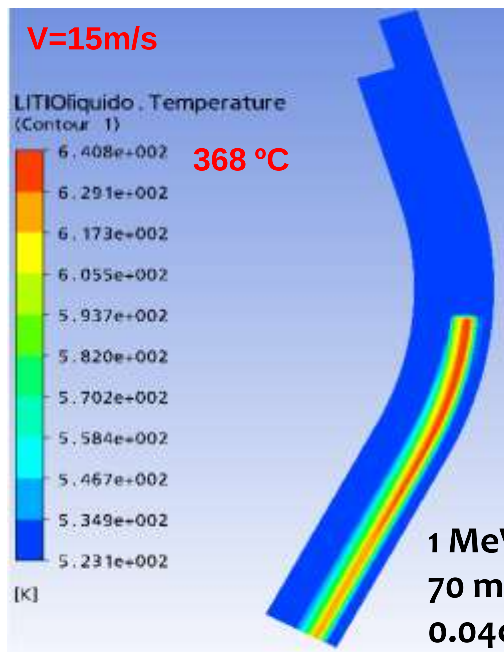
Several CFD simulations have been performed using different configurations of beam focalization and lithium velocity.

CONCLUSION: Different heat deposition configurations are possible in order to study its influence on free surface stability, lithium evaporation, etc.

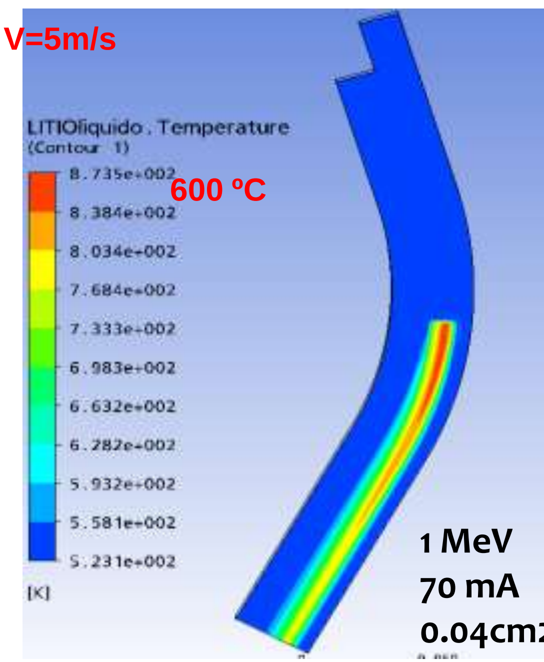
21 KW/cm3 ΔT : 27ºC



3000 KW/cm3 ΔT : 118ºC



3000 KW/cm3 ΔT : 350ºC



CONCLUSIONS

- For the development of the future fusion technology program, it is planned to build a set of relevant facilities (TECHNOFUSION) in Madrid, Spain, providing new tools to the Nuclear Fusion Energy Community.

- One of this facilities will be a Liquid Metal Laboratory that will consist of a modular liquid lithium loop with several experimental areas.

- In the LML it is foreseen the performance of experiments of free surface behaviour and materials corrosion (including electrons from one accelerator and vacuum conditions), MHD effects, purification and safety. As it will be a part of TECHNOFUSION, its interface with other laboratories and facilities means an additional value

- Furthermore, one of the LML objectives will be the validation of design tools: CFD codes, as an example.

- LML has, among their main objectives, the aim of be established as a meeting point for the liquid metals experts in the fusion field. The creation of a scientific users network will be also very useful in order to take advantages of the facilities

- Synergies with other fields could lead to an extended scientific users network

Thank you

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Liquid lithium applications: Fusion blankets

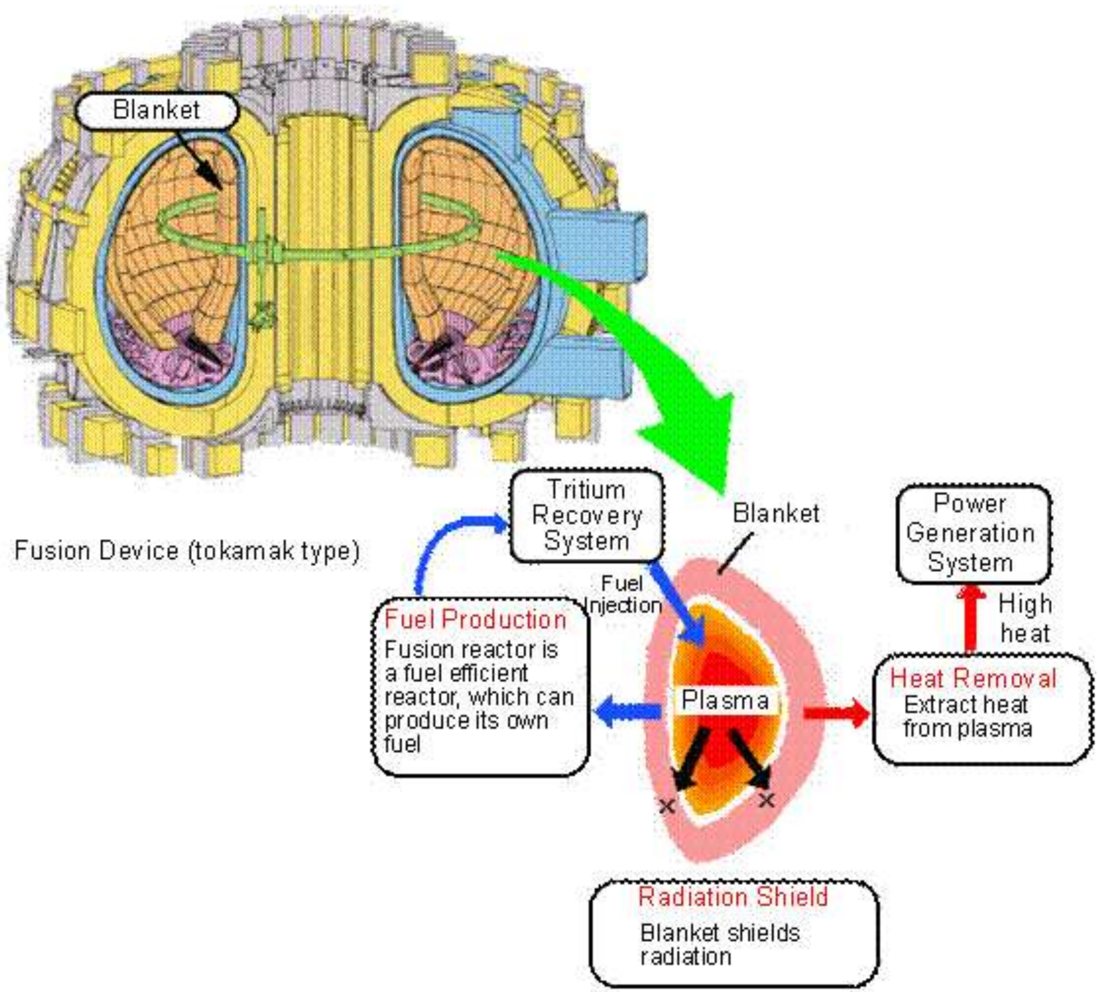
Blanket: *in a fusion power plant, is the system surrounding the plasma used to slow down the neutrons produced, so that the heat released can be used for electricity generation.*

The blanket is also used to synthesise tritium (from the neutrons and a lithium compound) to use as fuel.

Also acts a radiation shield for the superconducting coils

Functions of Generic Blanket

- **Heat Removal**
- **Tritium Production**
- **Radiation Shielding**



Rolls of Blanket

Liquid lithium applications: Fusion blankets

Main available breeders (Li-based compounds):
- Li-ceramics: Li_4SiO_4, Li_2TiO_3, LiO_2
- Liquid lithium (7.5% ^6Li)
- Eutectic Pb-17Li
- Molten salts: FLiBe, FLiNaBe

"Solid breeders"

"Liquid breeders"

Dominant issues: ***MHD, chemical reactivity for Li, tritium permeation for LiPb. Molten salts: melting point, chemistry, tritium control***

Neutron multipliers:
- Be (n,2n)
- Pb (n,2n)
- ^7Li (n, n´T)

Liquid breeders Concepts:

1 Separately cooled:

-A Separate coolant, tipically He, is used. The breeder is circulated at low speed for tritium extraction.

2 Dual coolant:

-First Wall (highest heat flux region) and structure are cooled with a separate coolant (He), to keep the temperature of the structure (FS) below 550ºC

-The liquid breeder is self-cooled: in the breeder region, the liquid serves as breeder and coolant. The temp. of the breeder can be kept higher than the structure one, leading to higher thermal efficiency.

3 Self cooled blanket:

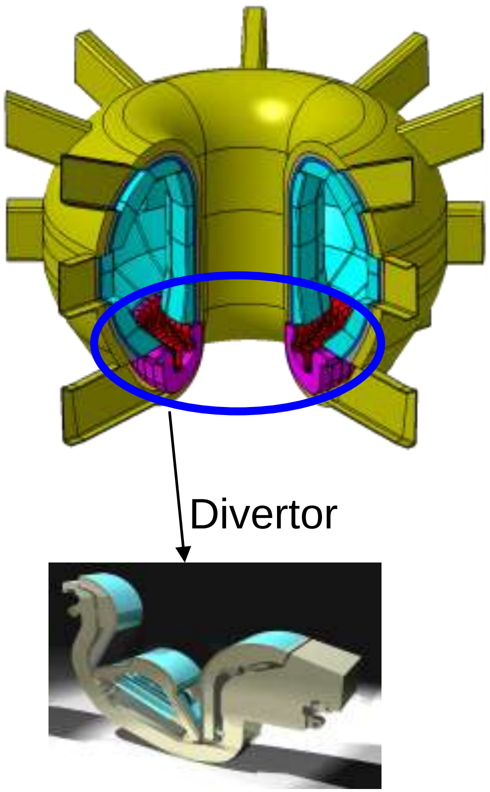
- Liquid breeder circulates at high speed to serve as coolant

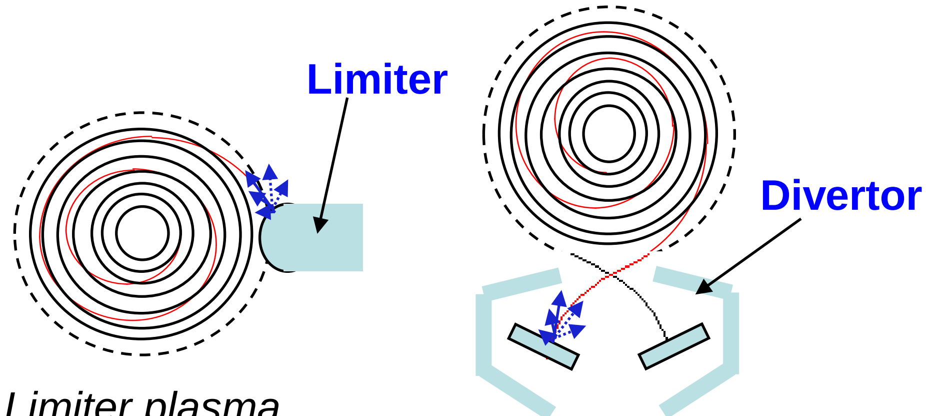
Main structural materials:
- Ferritic/Martensitic steels
- Vanadium alloys
- Composites SiC/SiC

LM blankets have the potential for:
- High heat removal
- Adequate T breeding ratio without n multiplier (in Li and LiPb)
- Relatively simple design
- Low pressure, low pumping power (if MHD problems can be overcome)

Liquid lithium applications: First wall, divertors and limiters of new concepts of nuclear fusion reactors

• In order to maintain the purity of fusion plasma, the interface of the plasma with the chamber wall is directed to some specific areas by means of special magnetic configurations:



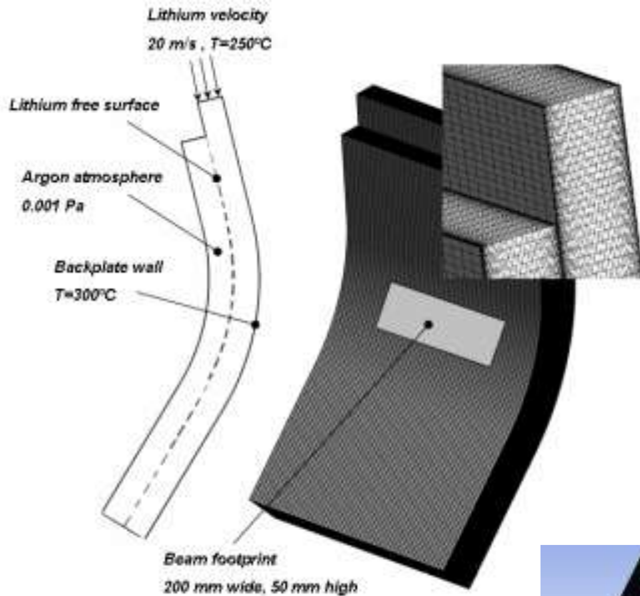


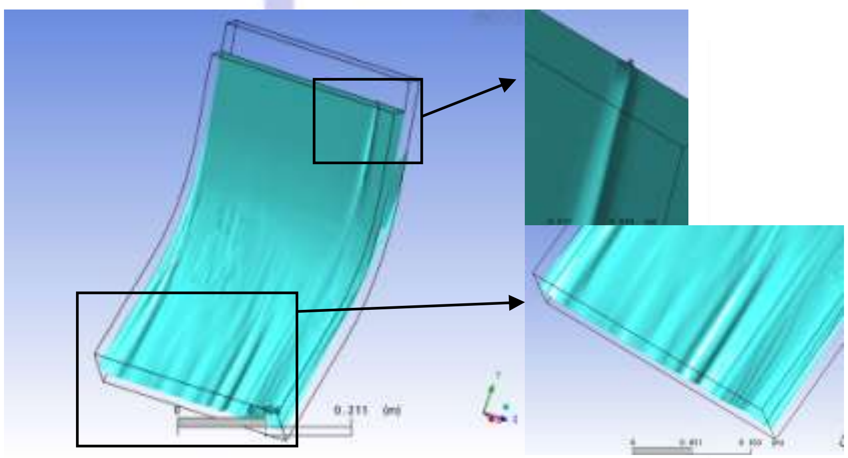
Limiter plasma configuration

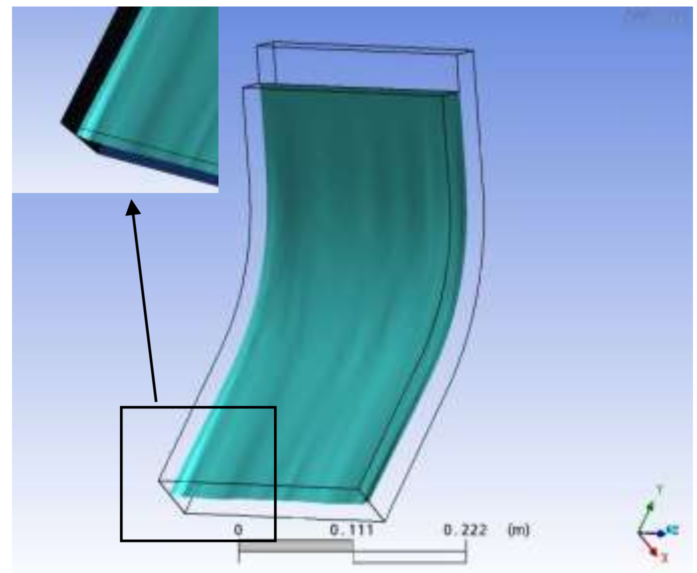
Divertor plasma configuration

✓ Therefore, the Divertors and the Limiters are cooled components that must be designed to withstand huge heat and radiation loads. Same happens with the First Wall of fusion reactors.

✓ New concepts of fusion reactors envisage **flowing liquid metal walls** as part of these components







Calculations under problematic situations as a small solid lithium drop (1 mm) in the nozzle exit edge. First attempt.

Free surface waves at 20 m/s where we can observe the lateral walls effect (longitudinal waves).