The Liquid Metal Laboratory of TECHNOFUSIÓN Facility

A. Abánades[1], N. Casal[2], F. Sordo[1], A. Ibarra[2], J. M. Perlado[1], A. García[2], R. Vila[2], M. González[2]

(1) IFN, ETSII, Universidad Politécnica de Madrid, P. Castellana, 28006, Madrid, Spain
(2) Laboratorio Nacional de Fusión por Confinamiento Magnético, CIEMAT, Av. Complutense, 28040, Madrid, Spain

abanades@etsii.upm.es

Abstract

The future commercial production of electricity based on thermonuclear fusion requires the development of a number of research projects, in addition to ITER, mostly related to the progress of long-term technologies that will be needed for future fusion reactors. For the development of the future fusion technology programme, it is projected to build a relevant set of facilities in Madrid, Spain, providing new tools to the Nuclear Fusion Energy community. Among the priority areas identified in the framework of international fusion research programmes, the proposed centre, TECHNOFUSIÓN, will focus primarily in the following: demonstration facilities for remote handling, radiation effects in structural and functional materials using several ions-electrons accelerators, plasma-wall interaction using a plasma gun in consonance with a perpendicular quasi-stationary plasma accelerator, advanced manufacturing technologies, liquid metal technologies and computer simulation, all being reinforced with the support of a significant set of advanced characterization techniques. Currently no similar facilities to TECHNOFUSIÓN exist, so it will provide more realistic tests than those available in other facilities up today, helping in the fast track to ITER, DEMO and IFMIF.

In particular, the Liquid Metal Laboratory of TECHNOFUSIÓN will consist on a liquid lithium facility with several experimental ports. The research scope of this Laboratory will be corrosion and materials compatibility, magnetohydrodynamic effects, component development, mechanical materials behaviour, physical/chemical properties of liquid metal and impurity effects, irradiation in liquid metals, thermal hydraulic behaviour, safety and validation of design tools with liquid metals. Some of these experiments will require the interaction with other TECHNOFUSIÓN facilities.

This contribution summarizes the technical requirements of the liquid lithium loop and the definition of main experiments to be performed on it.

1. Introduction

The development of thermonuclear fusion is one of the most important technological challenges for the scientific and engineering community, not only for the milestone related to the birth of a new energy production system, but also for the impressive amount of scientist, engineers, industries, and economical resources that are involved in a world collaborative project.

The practical international collaboration is focused in the design and construction of huge and complex facilities, as ITER, [1], and DEMO in the quest for a fusion device, or IFMIF, [2], for technological support (figure 1). Fusion technology is in the edge of the human knowledge for many engineering aspects due to the extreme conditions in which many materials and systems should work. This is true in the case of many common materials as stainless steels or materials for the solenoids of the confinement magnets. As an example, a huge effort is also in progress to understand, simulate and develop structural materials that could hand the radiation damage and activation that will occur in the first chamber wall of a nuclear fusion reactor.

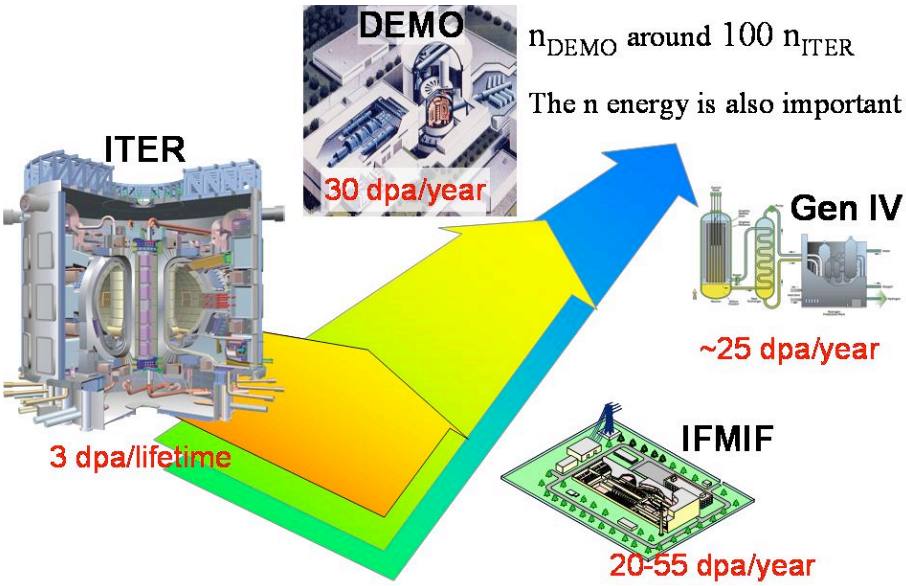

Figure 1: Expected damage production in ITER, DEMO, IFMIF and Gen IV projects

The construction of a prototype of an industrial fusion device from its proven physical principles is an apparent small step on the desk, but a large jump from the technological point of view. The large amount of resources involved in projects as the above mentioned requires the successful development of projects related to technological issues related to several aspects: materials, design tools, magnetohidrodynamics, liquid metal technology, and so on.

In this communication, we are going to address the Technofusion initiative that has been initiated in Spain to boost R&D in fusion technological issues.

2. Technofusion.

For the development of the future fusion technology programme, it is planned to build a relevant set of facilities in Madrid, Spain, providing new tools to the Nuclear Fusion Energy community. Such project has been initiated in the framework of an agreement between the regional government of Madrid and the Spanish Science and Innovation Ministry, with CIEMAT and UPM as main technical responsible of the consortium, but with the commitment to serve as booster for the participation of other universities, technological centres and engineering companies interested in the development of fusion technology. Although there is a Spanish initiative, the main objective of Technofusion is to contribute to the international effort towards Nuclear Fusion Energy Fast-Track with the inclusion of different facilities available for international collaboration in the field. Such facilities address horizontal technologies that could be of interest in other scientific areas as transmutation of nuclear wastes, or Generation IV.

Technofusion activities are focused on technological issues as the radiation effects on structural and functional materials using simultaneous ions and electron accelerators, evaluation of plasma interactions with first wall materials, development of advanced manufacturing technologies and corresponding materials characterization, improvement of liquid metal technologies, computer simulation and robotics and automation for Remote Handling (RH) including under irradiation operation.

The set of facilities that are now in the phase of conceptual design are linked to the technological objectives of Technofusion, being the following:

I. Material production laboratory.
II. Irradiation facilities (proton, electron).
III. Material characterization laboratory.
IV. Plasma-wall interaction laboratory.
V. Simulation laboratory.
VI. Liquid metal technology laboratory.
VII. Remote handling system laboratory.

In the following sections, we will describe the philosophy and status of the liquid metal laboratory.

3. Liquid metals in fusion technology.

Liquid metals are very interesting fluids for fusion applications because of their neutronic and thermo-physical properties, and have been proposed for many new innovative nuclear power systems, as transmutation of nuclear waste or isotope production devices.

The special characteristics of liquid metals make them very interesting for being used in several applications related to the fusion technology. Their neutronic and thermal hydraulic properties have led to propose some of them as part of a number of critical components for the future fusion reactors. This is the basis and one of the main reasons for the development of technologies associated to liquid metals in the framework of the design of fusion reactors such as ITER, [1] and DEMO.

Several concepts for breeding blankets (fig. 2) are proposed for the most important magnetic fusion concepts in progress. This is the case of the ITER project, where a very demanding technological program has started, in particular for the blanket modules, for which several breeding blankets concepts will be tested. One of the European proposals for Test Blanket Module (TBM) for ITER is a concept where the Lithium Lead eutectic is cooled by Helium with liquid metal flowing at very low velocities (< 1 mm/s). Other TBM concepts, as proposed by China and United States for ITER manage liquid metal flows up to 10 cm/s.

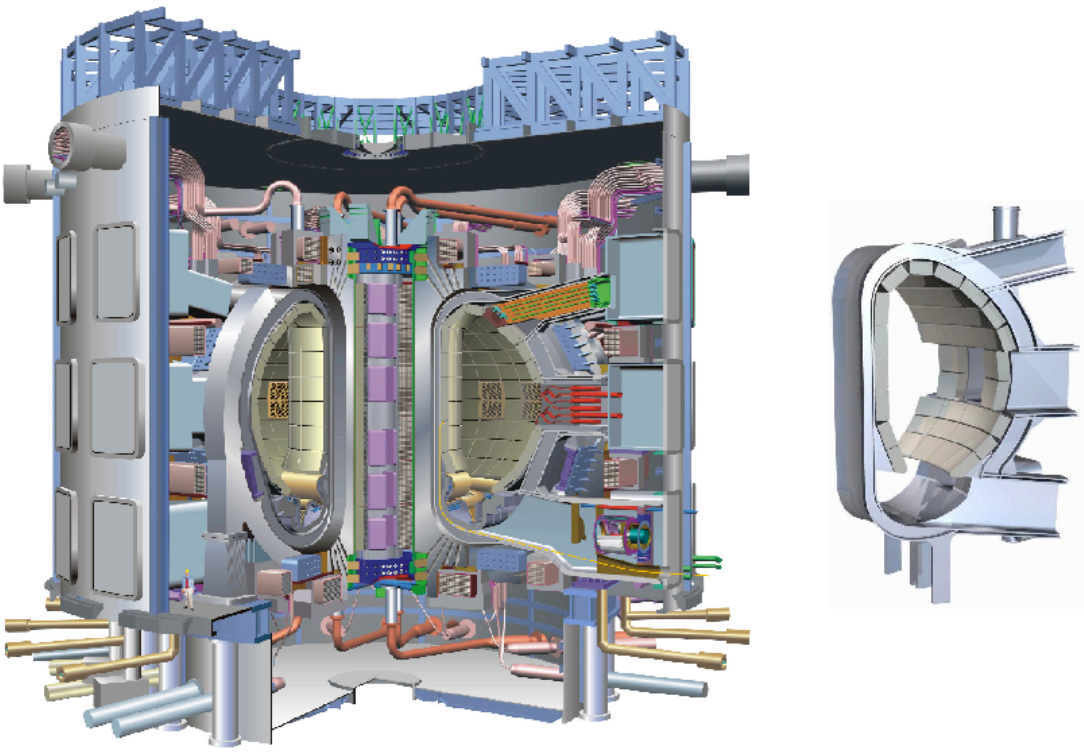

Figure 2: The ITER device and blanket

The work that is in progress for the DEMO design is considering several possibilities of Lithium Lead Eutectic (LLE) breeding blanket concepts, as the Helium-Cooled LLE (HCLL), the Dual-Coolant LLE (DCLL), [3], and the Self-Cooled LLE (SCLL), that have in common the utilization of Pb-17Li, either cooled by Helium or the liquid metal eutectic itself. In every of this concepts, liquid metal LLE has an important role, in many cases as the main coolant of the blanket design, what address the need to complete a huge R&D program to deeply understand the behavior of liquid metals for the design of the fusion devices that are planned in the medium term.

The American ARIES spherical torus **¡Error!No se encuentra el origen de la referencia.** concept is another fusion device that has the eutectic Lead-Lithium has one of its base materials. Its power core uses and advanced dual-cooled breeding blanket with flowing Pb-17Li breeder and Helium cooled ferritic steel structures that can obtain high thermal conversion efficiency. One of the R&D concerns that has been identified **¡Error!No se encuentra el origen de la referencia.** is the limited data available for the eutectic Lithium Lead that affects material compatibility with the proposed SiC and ferritic structural materials.

For the long term, other innovative concepts, like a liquid lithium wall in direct contact with plasma (fig.2) could bring some advantages such as plasma Stability and Confinement, a high Power Density Capability, reduced Radiation Damage in Structural Materials and also an expected high Availability, [6, 7].

In fusion technology development, IFMIF is also a reference installation for material testing 0 where neutrons for activation are produced by deuterons impinging a Lithium target, as shown in Fig.3. The thermal-hydraulic description of this liquid metal target is very challenging in the present state of the art of CFD simulation due to the approach that should be done to problems like free surface modeling, added to the description of thermal and velocity boundary layers and heat generation with liquid metals. There is international work in progress to assess the thermal-hydraulic behavior of this Lithium target 0 where the need of CFD code validation was shown to determine turbulence model choice and near wall function treatment.

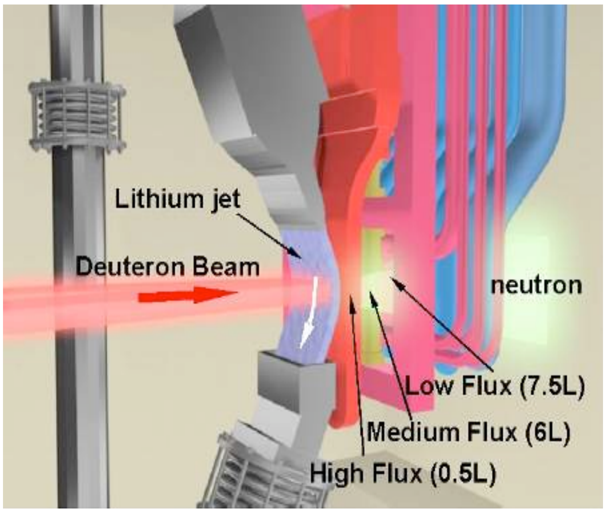

Figure 3: Liquid lithium at IFMIF facility

4. The liquid metal laboratory proposal for Technofusion.

The present status of liquid metals R&D and its technological application makes necessary the creation of new scientific and technological infrastructures that will allow fulfilling the following objectives:

- The acquisition of the key technological information needed to use the liquid metals in fusion technologies, in subjects such as:
    - Free surface behaviour (including electrons from one accelerator and vacuum conditions), [10]

    - Corrosion (including electrons from the electron accelerator),[11]
    - MHD effects, [12]
    - Purification
    - Safety, [13]
    - Validation of design tools

- The training of scientists and engineers, to design and undertake industrial tasks based on the use of liquid metals
- The technological transfer among R&D Facilities, Universities and Industry, to establish competent human resources for the deployment of future fusion devices.

An internal analysis of the present status of R&D and technology related to liquid metals in the framework of fusion development programs shows that the list of facilities concerning liquid lithium technologies is limited. For that reason, a lithium loop has been proposed, including new capabilities allowing the development of experiments such as the free surface plus heat deposition. This experiment is of utmost importance to support the design of IFMIF.

The experimental capabilities of the laboratory will be expanded by the design of experiments in collaboration with other facilities in the same site, having the possibility, for instance, to study liquid metal flow, steel corrosion and mechanical behaviour on liquid metal under irradiation, or heat deposition in a liquid metal flow in conjunction with irradiation facilities, or material characterization facilities. Such experimental activities will be highly supported by a computational laboratory in the design of experiments and engineering computing tool validation.

We foresee to have the technical capacity to support experiments as:

- Analysis of free-surface instabilities under vacuum conditions.
- Analysis of liquid lithium interaction with proposed fusion materials as steels (Eurofer, graphite, Be,…)
- Magneto-Hydrodynamic experiments.
- Analysis of lithium enrichment techniques.
- Test of auxiliary systems as Tritium extraction or liquid metal purification.

5. Development of the project.

The project development is foreseen in two steps. The first step will develop the basic infrastructure of the lithium loop, what will allow making same experiments related to material properties or fluid-mechanics validation. The second step will address the required upgrading for free-surface experiments with heat deposition, what would imply the fulfilment of more strict safety and legal normative and administrative reporting to the nuclear regulatory body due to the need of external radiation. Nevertheless, this approach in two steps is sensible as:

- The technological risk is reduced and is applied in a lower cost installation respect to the complete development of the laboratory.

- It will increase the technological experience of the partners in the project respect to this kind of installations that it is one of the weak points in the consortium, as there is a lack of liquid metal loops in Spain.
- There is a reduction of safety related requirements as lithium inventory is reduced.
- In this first step, Nuclear Regulatory normative is not applicable as there is no radiation.

During the next four years different activities will be performed in parallel. On one hand, the detailed engineering design tasks will start, altogether with the construction of the basic technological infrastructure. On the other hand, a training program will be set up, in order that the scientists and engineers could acquire the adequate capabilities to fully operate the Laboratory.

The project development for the first basic installation will be organised in the following phases:

1) Final choice of technical options and technical specifications of the Laboratory

This first phase will allow establishing the final technical specifications in order to perform the detailed engineering design of the Laboratory.

2) Final definition of the technical and R&D objectives, and development of scientific users networks

Taking into account the foreseen objectives of the Laboratory and the map of Spanish and International capabilities, a number of R&D lines have been already identified. Some of these research tasks should be integrated into the International Programmes related to the development of fusion technology, such as ITER and IFMIF, among others.

3) Detailed design of the Laboratory

This design is the engineering task that will fully define the facilities and the related costs, considering the possible suppliers, who will give the accurate data concerning costs and delivery times, in order to implement them in the final planning.
During this phase, fully interaction among the loop designer's team and the scientific groups which propose the experiments to be installed is needed.

4) Civil Works

Once the detailed design was performed, following the necessary authorizations, the construction of the Laboratory building could be started. This phase will have to be coordinated within the overall TECHNOFUSION schedule.

5) Construction of the liquid metal loop

The construction of the liquid metal loop could be started once the main part of the facilities construction was finished. The different components of the loop can be procured and assembled in their final location: pumps, pipes, auxiliary systems, power supply systems, safety systems, etc.

6) Safety and licensing studies

The assessment of the licensing process for the facility must be performed since the first phases of the project. The required technical reports and/or environmental impact studies will have to be delivered in order to obtain the necessary authorizations. All this work will have to be done in close cooperation with the correspondent team of the TECHNOFUSION facility. Preliminary contacts with the Spanish Nuclear Regulatory Commission (CSN) will be started to be ready for the next step in the project.

7) Commissioning

Finally, a commissioning protocol will be developed in order to start the Laboratory operation once the required authorizations are obtained. First, the correct operation of the lithium loop will be checked and its components fully tested. Then, some of the proposed experimental activities could be tested.

The foreseen schedule for the previously described phases is four years. Nevertheless, this planning could change, since these activities must be coordinated with the overall Technofusion schedule, and they also depend on the obtaining of the required authorizations for the construction and operation of the facility.

A fine cost evaluation of the facility is still pending on the detailed engineering studies. Preliminary estimation of the cost with large uncertainties suggest a capital investment of the order of 4,5 M€, with an estimation of additional yearly 640 k€ as O&M costs.

6. Conclusion

A brief description of the liquid metal laboratory that is foreseen in the framework of the Technofusion project, that is starting under the umbrella of the regional government of Madrid and the Spanish Science and Innovation Ministry, with CIEMAT and UPM as technical partners in a consortium.

In particular, the Liquid Metal Laboratory of Technofusion will consist on a liquid lithium facility with several experimental ports. The research scope of this Laboratory will be corrosion and materials compatibility, magneto-hydrodynamic effects, component development, mechanical materials behaviour, physical/chemical properties of liquid metal and impurity effects, irradiation in liquid metals, thermal hydraulic behaviour, safety and validation of design tools with liquid metals. Some of these experiments will require the interaction with other Technofusion facilities.

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