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IAEA nuclear fusion

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To cite this article: Y. Hirooka *et al* 2023 *Nucl. Fusion* **63** 097001

OPEN ACCESS
IOP Publishing | International Atomic Energy Agency
Nuclear Fusion
Nucl. Fusion **63** (2023) 097001 (11pp)
https://doi.org/10.1088/1741-4326/ace6bd

Conference Report

Conference Report on the 7th International Symposium on Liquid metals Applications for fusion (ISLA-7)

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Received 1 May 2023, revised 15 June 2023
Accepted for publication 12 July 2023
Published 28 July 2023

Abstract
Supported by the world magnetic fusion research community, a series of International Symposia on Liquid metals Applications for fusion (ISLA) have been held biannually since 2010. The 7th edition (ISLA-7) was held for the period from 12 December through 16 December 2022, at Chubu University located in Kasugai, Aichi, Japan. For the first time in the history of this series of symposia, ISLA-7 was held in a hybrid fashion, due to the COVID-19 situation. The total number of the participants was 60, 34 out of whom attended the symposium in person, and the rest participated online. As to the presentation statistics, 29 papers were presented in person, whereas 21 presentations were delivered online but real-time by the presenters in China, Spain, the UK, and the USA. Both of the presentations delivered in person and online were recorded, and the video has been shared by all participants. These participants represent 11 countries: China, Czech, Italy, Japan, Latvia, Netherlands, Russia, Thailand, the UK, and the USA. All these numbers are among the largest in this series of symposia. Covered by these presentations are; in session-2, program overviews and liquid metal research review; in session-3, liquid metal flows, and MHD issues; in session-4, liquid metal facilities; in sessions-5 and 6, liquid metal experiments and modeling; in session-7, divertor physics and heat flux mitigation; in session-8, plasma and liquid metals interactions; in session-9 liquid metal plasma-facing components, erosion, and wettability. In addition, there were an opening session whereby several opening addresses were delivered and also a closing session where all technical session summaries were presented by the respective session chairs.

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Keywords: liquid metal applications, nuclear fusion reactor, plasma-surface interactions, divertor, plasma-facing components, liquid metal plasma-facing components, magnetic fusion DEMO reactor

1. Introduction

Briefly mentioned here for completeness are some of the technical issues associated with the divertor design which employs tungsten as the plasma-facing surface material brazed on an actively cooled heat sink. The heat sink is often made of copper alloys such as Glidcop, the thermal conductivity of which can be as high as ~350 W mK^{-1}. It is thus believed that this bilayer structure can manage the perpendicular divertor heat fluxes, estimated to be ~10 MW m^{-2} for ITER with the plasma heating power of 120 MW [1]. From the point of view of on-site radiation safety, however, the use of copper alloys will not be allowed for DEMO reactors such as SLIM-CS [2] for which the heating power can be as large as 645 MW. Used for the heat sink structure for SLIM-CS will probably be reduced activation steel alloys such as F82 H, the thermal conductivity of which ranges only 30–40 W mK $^{-1}$ [3], utterly insufficient for the removal of divertor heat fluxes.

Furthermore, it is widely recognized that the ductile-brittle transition temperature (DBTT) of tungsten is around 400 °C [4], which could go even higher with neutron irradiation. This means that the DBTT of tungsten will repeatedly be crossed by the temperature excursions associated with the ramp-up and -down operations of ITER as well as DEMO. As a result, the tungsten surface component will unavoidably suffer from thermal fatigue cracking.

From the separate experience associated with the development of Li-D neutron sources such as IFMIF, one has learned that liquid lithium (LL) flowing at velocities of 10–20 m s^{-1} can take heat fluxes of the order of 1GW m^{-2} [5]. For liquid metals, DBTT is clearly not a technical issue. Moreover, lithium coatings put down on the Plasma-Facing Components (PFCs) have led to reduced wall recycling, which then resulted in the confinement improvement in large plasma confinement devices such as Tokamak Fusion Test Reactor [6]. These have motivated the development of liquid-metal PFCs (LM-PFCs). On the other hand, it is also true that the high-recycling mode of operation, perhaps together with impurities injection has successfully been applied in Joint European Torus [7] so that the divertor heat flux could be reduced. It is thus too premature and totally beyond the scope of this conference report to discuss which is better the low recycling or high recycling mode for DEMO reactor operation. Nonetheless, it is undeniably true that the divertor heat fluxes predicted for DEMO from the magnitude of plasma heating power would be far more than those to be seen in ITER. Therefore, it has generally been agreed that the development of LM-PFCs that can handle DEMO-relevant divertor heat fluxes is the most urgent task.

This historical background has motivated the world magnetic fusion research community to put together a new forum where those who are interested in LM-PFCs can discuss and exchange ideas, which then has led to the initiation of the International Symposia on Liquid metals Applications for fusion (ISLA) series of symposia. To briefly review the history, the ISLA series of symposia have been held biannually since 2010: the 1st edition was hosted by Y. Hirooka at NIFS, Japan in 2009 [8], the 2nd one by M. Ono at PPPL, the USA in 2011 [9], the 3rd one by G. Mazzitelli at ENEA, Italy in 2013 [10], the 4th one by F.L. Tabares, CIEMAT, Spain in 2015 [11], the 5th one by S. Mirnov at TRINITI, Russia in 2017, and the 6th one by D.N. Ruzic at Univ. Illinois, the USA in 2019 [12].

Then, the 7th symposium was first planned to be held at ASIPP, China in the fall of 2021, which, however, was postponed due to the COVID-19 situation, and early in 2022 the situation did not yet seem to be improved at all. In order to avoid further delay, therefore, the ISLA International Organizing Committee recommended that the 7th edition be hosted again by Y. Hirooka late in 2022 at Chubu University, Japan. Throughout the history of this series of symposia, essentially all papers have been orally presented, except for a limited number of poster presentations. This good and old days' tradition came back with ISLA-7, the details of which will be described in the next section.

2. Symposium summary for the technical sessions

Session 2 on Program overviews and LM experiments, chaired by M. Ono of PPPL, the USA.

In session 2, 3 invited papers and 2 contributed papers were presented.

The session started with an invited paper by J.S. Hu of ASIPP, China, entitled 'Recent activities on flowing liquid Li limiter experiments in EAST.' It should be noted that due to the COVID-19 travel restriction, all the presentations for ISLA-7 from China were delivered online. The EAST tokamak has been used as a testbed for the development of LL based PFCs over the past years. Utilizing lithium wall conditioning techniques, the EAST tokamak has successfully demonstrated long-pulse plasma discharges, including 1000 s L-mode shots and also 300 s H-mode plasma shots. The Flowing LL (FLiLi) PFC was first introduced as a limiter in EAST back in 2014. Since then, FLiLi has been upgraded with various improvements. Recently, the fourth generation FLiLi has been developed and tested in EAST. Based on the test data one expects that the latest version of FLiLi can be a promising candidate PFC in the future fusion DEMO reactor. The recent upgrade of FLiLi with a TZM (titanium, zirconium, molybdenum) alloy substrate with surface trench structure, using the TEMHD principle and gravity force, has enabled liquid Li to flow on the substrate with an 87% surface wetted coverage. In fact, after an experimental campaign, no obvious damage has been observed on the FLiLi surface. The compatibility between liquid Li and materials in contact has also been investigated, the result of which can provide valuable information for future experiments. It is believed that a liquid Li divertor with a 3D-printed tungsten substrate will be developed in the future.

The second invited paper, entitled 'Liquid metal PFCs designs for fusion devices' was presented in person by R. Maingi of PPPL, Princeton University, the USA. This talk overviews the activities with the US program to identify the LM-PFC design windows for FNSF for the Fusion Nuclear Science Facility. The design goal is to develop a viable LM-PFC concept for a nuclear device, i.e. FNSF or FPP for the Fusion Pilot Plant. The design choices are based on the assumptions that (1) lithium (Li), (2) divertor, and (3) flowing PFCs are implemented in FNSF and/or FPP. However, there are obviously several design issues, including the Magneto-Hydrodynamics (MHD) flow instabilities associated with liquid Li pumping through a magnetic field, plasma-materials interactions, and corrosion/erosion/embrittlement of structural materials. Despite all these technical issues, the following progress has been made. A design window to operate liquid Li divertor PFCs with low evaporation (i.e. <450 °C) has been identified for a simplified "3-leg" geometry for FNSF. Single effect test stands studied wetting characteristics with an integrated Li loop. Linear channel flow experiments are validating the same LM flow code used for the FNSF design. A pre-conceptual design is being initiated for NSTX-U Li-PFCs, based on the FNSF design concept. Considerable progress has also been reported on the novel divertorlets concept.

The third invited paper, entitled 'Observations of convection effects on particles and heat transport in liquid metals under plasma bombardment and infrared irradiation' was presented in person by Y. Hirooka of Chubu University, Japan. This presentation gives an overview of the LM PFC Proof-of-Principle experiments performed by the group in Japan in 2000–2015 at NIFS, using a linear plasma facility called VEHICLE-1. It was found that both natural and forced convection could enhance particles and heat transport in liquid metals (GaInSn and liquid Li) under steady-state plasma bombardment and infrared irradiation. Here, the natural convection in these experiments was introduced with a resistive heater placed at the bottom of a liquid reservoir. Interestingly, natural convection has been shown to be hindered by a mesh placed in the mid-depth region, indicating that a certain depth of liquid is required for natural convection to occur. A simple manual paddle was also used in the first-of-a-kind experiment to demonstrate the effect of forced convection, which resulted in reduced particle recycling. In addition, a series of $\mathbf{J} \times \mathbf{B}$-forced convection experiments were conducted, and enhanced particles transport in GaInSn and LL has been observed, which then was referred to as "Vortex Pumping Effects." In these experiments, the $\mathbf{J} \times \mathbf{B}$-forced convection was introduced with a DC current between two electrodes, crossing the applied magnetic field. In 2015–2020 at Kyushu University, the $\mathbf{J} \times \mathbf{B}$-forced convection has been observed to enhance significantly heat transport in GaInSn under infrared irradiation. In the meantime, the VEHICLE-1 facility was relocated from NIFS to Chubu University. The latest experiments in VEHICLE-1 have been intended to demonstrate that $\mathbf{J} \times \mathbf{B}$-forced convection can reduce particles recycling and at the same time enhance heat transport. However, only the enhanced heat transport has been observed so far, suggesting that more DC-current is necessary or the electrodes should be moved closer to the surface to induce more perturbation for vortex pumping effects.

The next contributed oral presentation, entitled 'Physics basis for design of Liquid Metal Divertor (LMD) on tokamak COMPASS Upgrade' was delivered in person by J. Horacek of the Czech Academy of Science, Czech. The COMPASS-Upgrade (COMPASS-U) device is a new cryogenically cooled (-200 °C) high field (5T) high divertor heat fluxes up to 90 MW m^{-2} to be completed and readied for the LM-PFC operation in $\sim$2027. Its predecessor COMPASS device has a lower field (1.6T) and lower divertor heat fluxes ($\sim$1.3 MW m^{-2}). The Capillary Porous System (CPS) concept has been implemented with the divertor. An LL-based CPS did not work well as LL is found to be rapidly depleted, which then damaged the CPS mesh surface. As opposed to that, lithium tin (LiSn) has performed quite well despite the preferential erosion of Li observed. As for COMPASS-U, pure Li is not possible due to the lack of inlet/outlet pipes for liquid transport and the resultant surface oxidation. A single LMD unit standing, inclined at 45° on the toroidal divertor plate has survived a heat flux of $\sim$160 MW m^{-2}, but significant plasma dilution and strong core radiation have been observed. For a full toroidal divertor, a pure Sn-LMD may be favored, because of no inlet/outlet pipes and a cold trap required, although noticeable core radiation might occur. For the full LiSn toroidal divertor, radiation collapse could occur and the liquid LiSn in a reservoir can only last for one week so it would not be recommended for COMPASS-U unless inlet/outlet pipes and cold traps can be installed.

The last contributed paper is entitled 'Performance of a liquid tin divertor target during ASDEX Upgrade L and H-mode operation,' presented in person by J.G.A. Scholte of Eindhoven Univ. of Tech., Netherlands. A CPS-based divertor module in the size about 40 mm $\times$ 16 mm has been manufactured, using the 3D printing technique. The CPS module was filled with 1.5–2 grams of liquid tin, and placed in the divertor strike-point region. The exposure to the L-mode ASDEX-U discharges with the divertor peak heat flux of $\sim$0.6 MW m^{-2} appears to have caused no technical trouble. On the other hand, the H-mode discharges, producing much higher divertor heat fluxes of $\sim$5 MW m^{-2}, have resulted in the leakage of liquid Sn from the edge areas of the CPS module, and also ended up forming Sn droplets. This resulted in an unacceptable level of core Sn contamination in the core plasma. The future tasks include the investigation of Sn droplets formation and liquid leakage.

Session 3 on liquid metal flows and MHD, chaired by A. de Castro of CIEMAT, Spain

Within the session, seven contributed papers were presented covering both computational and experimental works on liquid metal flows and related MHD.

R. Hiraka of Kyushu University, Japan, presented in person a contributed paper, entitled 'Closed loop system for observation of liquid metal flow in magnetic field.' Shown in this presentation are the results of observations of GaInSn, flowing on a 45° inclined slope at velocities up to 1 m s^{-1} in a variable magnetic field up to 1.0 T. The liquid metal is circulated by the use of a diaphragm pump. Surface waves were observed on the free surface of GaInSn at magnetic fields beyond 0.4 T, which was qualitatively corroborated by fluid dynamic simulation. Additionally presented were some of the future work plans, including the design and installation of a closed-loop system circulating GaInSn.

M. Shimada, formerly of QST, Japan, presented in person a contributed paper, entitled 'A duct design for reducing grad-**B** MHD drag.' In this work, MHD characteristics of a liquid metal flow with varying duct geometries along with **B**-grad are analyzed. Modeling analysis has been done to explore the possibilities of reducing the MHD drag, and related pumping power needed for a fast-flow liquid metal PFC. The MHD drag in the case of uniform **B**, estimated analytically, is acceptable. Although the grad-**B** MHD drag with straight ducts could seriously drag the LM flow across non-uniform **B**, expanding the duct along **B** and shrinking the duct in a perpendicular direction could make electromotive force |v*B*h| approximately constant along the duct, significantly reducing the grad-**B** MHD drag, where *v, B*, and *h* are the flow velocity, the magnetic field strength, and the vertical duct size, respectively.

N. Mburu of Oxford University, the UK, presented in person a contributed paper, entitled 'Liquid metal free surface flow in transverse and surface normal magnetic fields,' reporting on the design and the first experiments done using a new facility to characterize MHD and TEMHD effects on a liquid metal flow in a magnetic field at strengths up to 0.34 T in both transverse and surface normal field directions, covering different configurations where spatial fields are varied, eventually presenting a higher field strength at locations with smaller gap spacing. The experiments, currently underway, will provide the data on the effects of the magnetic field, orientation, plate angle, and flow rate on the fluid depth. Furthermore, technological efforts and methods attempting to improve surface wetting were explored, including the reduction of surface roughness which has led to a measurable reduction in contact angle. Finally presented was the future plan for computational modeling, using the ANSYS CFX code with the main goal of extrapolating the experimental results to fusion reactor relevant conditions.

N. Erkan of UKAEA, the UK, presented online a contributed paper, entitled 'Validation study of Open FOAM MHD solver against a magnetic obstacle in GaInSn flow channel.' Computer simulation has been performed, the result of which has shown the flow and velocity distribution in different cases, identifying flow regions depending on particular positions in the LM channel. It has been found that the presence of a non-uniform magnetic field leads to the generation of sidewall liquid jets. Those jets then induce severe turbulence downstream of magnetic obstacles within a flowing LM. An OpenFoam software solver has been utilized in an induction-less approach to simulate and try to predict such a complicated flow, where a transition to turbulent occurred and complicated patterns appeared, depending on the main figures of merit of the fluid regime (Ha and Re numbers). All these results warrant further work in order to assess the phenomenology of more complex cases characterized by flow regimes with high Ha and Re numbers, being a question that will be addressed in the future work.

J.H. Pan of the University of Chinese Academy of Sciences, China, presented online a contributed paper, entitled 'The thickness of MHD film flow in an open channel.' Presented in this paper are the results from computational studies on a free surface LM flow within ducts made of conductive walls, intended to describe the liquid metal flow behavior controlled by the parameters including: the magnetic field, liquid metal flow and solid-liquid as well as solid-gas interfaces. Results from this analysis can be used as a guideline to design of a fast flow LM divertor if an empirical scaling law is provided, describing the LM film thickness (*h*) depending on several experimental parameters such as magnetic field, volume flowrate, inclination angle of the channel, and conductivity coefficient between the channel wall and the fluid. The fundamental relationship $h \sim \mathrm{Ha}^2$ (Ha being the Hartmann number) appears to be useful for the prediction and the extrapolation of the metrics of the LM layer within a tentative free surface divertor-like LM PFC element.

T. Han of the University of Chinese Academy of Sciences, China, presented online a contributed paper, entitled 'Spreading features of a liquid metal droplet under magnetic fields.' Presented in this paper are the results from numerical simulation of the effects of parallel and perpendicular magnetic fields on the behavior of an LM droplet that spreads when it falls onto a solid surface. Results indicate that the presence of a vertical magnetic field inhibits the droplet from spreading. Proposed for the first time here is a scaling law of $\beta_{\max} \propto N^{-1/2}$, where $\beta_{\max}$ is the maximum spreading radius and N is the surface interaction parameter, depending on the viscosity, capillarity, and wettability. In addition, anisotropic effects of the horizontal magnetic field on the behavior of a droplet spreading have been discussed. Finally, a model for predicting the maximum spreading area was proposed, based on an energetic analysis.

L. Buligins of Institute of Physics, University of Latvia, Latvia, presented in person a contributed paper, entitled 'MHD flow in simple cubic periodic array geometry,' describing the results from the ANSYS modeling on the MHD flows in the 3D-printed dielectric porous media with an opening size ranging ~mm and their comparison with experimental data, analyzing cases in the different flow regimes, dominated by electro-magnetic, viscous, and inertial forces. The pressure drop and related LM volumetric flow are characterized in a wide range of magnetic field strength. The main results showed qualitative agreement between the simulations and experimental data in the porous dielectric substrate, where the influence of parallel and perpendicular magnetic fields as well as pore size in the MHD dynamics have been observed. The possible extension of modeling to metallic CPS structures with pore sizes ranging from tens to hundreds of microns appears to be important in optimizing the CPS performance in terms of LM refilling/dry-out characteristics.

Session 4 on liquid metal facilities, chaired by Y. Hirooka of Chubu University, Japan

Presented in this session were 3 invited papers and 3 contributed papers, all on liquid metals PFC test facilities: 1 located in the Netherlands, 1 in Spain, 3 in the USA, and 2 in the UK.

As the first speaker of the session, T.W. Morgan of DIFFER, Netherlands, presented in person an invited paper, entitled 'An integrated laboratory for the development of Liquid-Metal Shield technologies for fusion reactors,' describing the details on the facility named LiMeS-lab: an integrated laboratory for the development of Liquid Metal Shield technologies for fusion reactors. In this paper, the existing and planned capabilities are described to evaluate in a systematic fashion liquid metal PFC concepts such as those employing the principle of CPS for Capillary Porous Structure. These capabilities include: 1. 3D-printing design capability for R&D on the porous microstructures for CPS-type PFCs to be made of tungsten, using the selective laser melting technique; 2. liquid metal wettability controlling capability based on the surface oxide formation/removal done by the exposure to atomic hydrogen as a reducing agent at elevated temperatures. Data indicate that tungsten is easier to be wetted with LL than with liquid tin under identical conditions, which can affect the material choice for CPS-PFCs; 3. steady-state plasma-interactions experimental capability by the use of a linearly magnetized ($\sim$1.5 Tesla) plasma generator with a plasma density of the order of 10^{20} m^{-3} and electron temperatures around 5 eV, which can produce heat fluxes up to 20 MW m^{-2}. Also developed for the plasma-interactions facility will be a target holder with a $\mathbf{J} \times \mathbf{B}$-driven liquid metal circulation system; and 4. Thermal desorption spectroscopy capability as part of the post-mortem analysis to be conducted on the samples exposed to plasmas. It is hoped that the first series of experiments using all these capabilities will be conducted in 2023.

A. de Castro of CIEMAT, Spain, also presented in person an invited paper, entitled 'Physics and technology research for liquid-metal divertor development at the OLMAT high heat-flux facility,' describing a high heat-flux plasma facility referred to as OLMAT for Optimization of Liquid Metal Advance Targets. Actually, the plasma generator for this facility has recently been converted from the neutral beam injector designed for the TJ-II stellarator. The OLMAT facility can generate heat fluxes ranging from 5 to 56 MW m^{-2}, consisting of hydrogen neutrals, containing a fraction of ions up to 33% in some instances at energies up to 33 keV, and at fluxes up to 10^{22} m^{-2} s^{-1} for the durations for 30–150 ms. These conditions are believed to be essential to evaluate LM-PFC concepts for a DEMO reactor. Importantly, the OLMAT facility is installed with various diagnostics, including: 1. an IR camera and multiple pyrometers to analyze the thermal responses of the test target; 2. an electrical (Langmuir) probe and optical spectrometry arrays to analyze the atomic and plasma physics of eroded materials such as tin. 3. Also available is a test target assembly which can be attached with a variety of CPS surface components through which liquid tin can be circulated. The first (commissioning) experimental campaign on liquid tin has already been conducted, the details of which will later be presented by E. Oyarzábal of CIEMAT, using 1. tungsten mesh supplied from CIEMAT; 2. tungsten felt supplied from ENEA, 3. Sintered tungsten and also a 3D-printed tungsten mesh, both supplied from DIFFER. More recently, a high-power Constant-Wave laser (that can work in both continuous and pulsed mode) has been added to the facility in order to mimic steady-state divertor-like power densities as well as transient events such as ELMs and disruptions.

A. Shone on behalf of D. Andruczyk, both of the University of Illinois, presented in person an invited paper, entitled 'Overview of Liquid Metal Research at the University of Illinois' to overview the recent activities using the LM-related research facilities, all located at the Center for Plasma Material Interactions of Univ. Illinois. 1. First reported was on the latest version of the FLiLi for Flowing LL limiter in EAST at ASIPP, China. This FLiLi allows the gravity-driven vertical flow of LL, cooled by helium gas and is aligned by the surface trenches, while there is a 'communication' between the trenched flows by the mechanism called TEMHD for Thermo Electric MagnetoHdroDynamics. The suppression of lithium evaporation by helium gas cooling has clearly been observed by optical spectroscopy. As a result, the edge electron temperature has increased, leading to the plasma confinement improvement in EAST. 2. Also reviewed are some of the latest experiments conducted in a stellarator named HIDRA and its associated facility: HIDRA-MAT for the Hybrid Illinois Device for Research and Applications and MAT for Materials Analysis Test stand. Data indicate that both hydrogen and helium are pumped by lithium evaporation followed by re-deposition, leading to a suppression of gas recycling from the first wall. Hydrogen pumping can readily be explained by the chemical affinity with lithium, whereas as to helium pumping, the co-deposition of lithium and helium seems like a plausible mechanism.

Presented in person by T. Marchhart of Penn State University, the USA, was a contributed paper, entitled 'Design of the Liquid-Metal In-Vacuo Injection System (LIVIn) in the IGNIS-2 Facility,' describing an on-going project to put together an experimental setup, named LIVIn for the Liquid-Metal In-Vacuo Injection System. This system is intended to inject in vacuum a liquid metal of lithium or tin into the open pores in a low-density tungsten material, prepared for a CPS-type PFC. The liquid metal is externally pressurized by argon, and then transported into a porous tungsten substrate held in the IGNIS-2 facility for Ion-Gas-Neutral Interactions with Surfaces V2. Porous tungsten media are prepared separately, using the place holder technique, whereby micropores are plugged with a de-alloyable element such as carbon during the compression sintering process. The first series of Proof-of -Principle experiments on LIVIn is currently being conducted in IGNIS-2.

S. Stemmley of the University of Illinois, the USA, presented in person a contributed paper, entitled 'Development of a LL Loop for a Low-Recycling Free-Surface PFC,' describing the present status of the development of a LL loop system for a TEMHD-implemented PFC, intended to achieve low-recycling conditions. Taking over from the traditional trench-style PFC setup, a new 3D-structured substrate has been introduced with a FLiLi-type PFC with a more stabilized TEMHD flow under high heat load conditions. For this setup, a new LL flow loop system has been developed, featuring an EM pump and automatic leak checking system, and tested in air, Ar and He, and also in vacuum. Results have indicated a rather uniform flow rate distribution in the width direction of the 3D-structured substrate.

P.F. Buxton of Tokamak Energy, the UK, a venture business company first funded in 2009 presented in person a contributed paper, entitled 'Advances in Tokamak Energy's lithium technology development from divertors to tritium recovery.' This paper describes the present status of the on-going design work on a spherical tokamak: ST40 to be operating for a fusion burn pulse of 900 s, followed by a recharge pulse of 100 s. Currently, a set of TEMHD-implemented divertor tiles with a traditional trenched surface, toroidally distributed for the double-null configuration, are considered for ST40. Detailed modeling is being done for the lithium flow along/over the trenches using the SOLEDGE2D-EIRENE code. Currently, two modes of plasma interactions are investigated for liquid droplet formation: 1. steady state interactions; and 2. transient events such as the start-up phase, ELMs, and plasma quench.

Session 5 on liquid metal experiments and modeling I, chaired by T. Bunting of Tokamak Energy, the UK

Presented in this session were 1 invited paper and 7 contributed papers, all on liquid metals experiments and modeling.

S. Abe of PPPL, the USA, presented in person an invited paper, entitled 'Recent progress on investigations into plasma-lithium surface interactions in LTX-β.' Overviewed first in this presentation are some of the important experimental facilities and techniques used in this work, including LTX-β for the Lithium Tokamak eXperiments equipped with Lyman-α spectroscopy (with a wavelength of 121.6 nm) and the Surface Science and Technology Laboratory equipped with SES for the Surface Exposure Station. From the Lyman-β data, rather flat and higher temperature and density profiles have been observed in LTX-β with fresh lithium deposits on the wall. Even in the edge region, the electron temperature stays above 200 eV. Importantly, it has been found that as more lithium is deposited on the surface, the energy confinement time increases and eventually becomes close to the particle confinement time, i.e. $\tau_E \sim \tau_p$. It has been found in the data taken from SES that lithium tends to be sputtered as secondary ions (Li^+), the kinetic energy of which seems to stay below $\sim$100 eV. This energy is equivalent to or even lower than the sheath potential when Te $\sim$ 200 eV, resulting in prompt redeposition of Li^+. These findings explain in part improved confinement in LTX-β with fresh lithium deposits on the wall.

C. Moynihan of the University of Illinois, the USA, presented in person a contributed paper, entitled 'Hydrogen extraction by thermal distillation in lithium loop systems.' First, the phase diagram of the H-Li system was reviewed to explain the experimental procedure and modeling done in this work. Assuming ignited ITER with a Li-divertor, circulating a dynamic tritium balance of $3 \times 10^{22}\,s^{-1}$, 0-dimenstional modeling on the tritium extraction process has been done in 3 possible cases: 1. hydrogen is released from the Li-H solid solution phase (α-phase); 2. hydrogen is released from the two phases: Li-H (α-phase) + LiH (liquid hydride: β-phase); 3. hydrogen is released via evaporation from a fully hydrogenated solid LiH (β-phase). Solving a set of simultaneous materials balance equations, cases#2 and #3 have been found to be applicable from the chemical engineering point of view because a steady state extraction can be predictable.

F. Romano of DIFFER, the Netherlands, presented in person a contributed paper, entitled 'A lithium vapor box design for experiments in the linear plasma generator Magnum-PSI.' Presented in this paper is a laboratory experimental setup to simulate lithium vapor-plasma interactions in the vapor box configuration, using the Magnum-PSI linear plasma device, located at DIFFER, intended to provide ITER-relevant divertor plasmas. The lithium vapor-plasma interactions zone of this setup is diagnosed with a variety of diagnostics, including Thompson scattering, optical spectroscopy, Langmuir probe, pyrometers and also a calorimeter positioned behind the magnum-PSI plasma dump. Experimental data have been analyzed, using the DSMC (for Direct Simulation Monte Carlo) SPARTA code, which has indicated a reduction by 60%–70% in particle flux reaching the plasma dump with the presence of lithium vapor. Also found is that the hydrogen ion flux decreases while the lithium ion flux increases, both reaching the plasma dump, due to the respective charge exchange processes. Future research plans include actual experimental investigation.

M. Perez Garcia of CIEMAT, National Laboratory for Fusion, Spain, presented online a contributed paper, entitled 'Application of the MELCOR fusion code to the transient accident analysis of the IFMIF-DONES target.' Overviewed first in this presentation is the IFMIF-DONES facility, defined as a first-class radioactive facility in Spain. The safety regulation is such that the facility design needs to ensure the maximum dose to the Most Exposed Individual due to the release of radioactive inventory be controlled not to exceed the established threshold. Then, two accident scenarios are hypothesized in the applications of the MELCOR fusion code, originally developed by Sandia National Laboratories and Idaho National Laboratory, both located in the States: (1) failure in the LL inlet nozzle of TVC for the Target Vacuum Chamber in which case less than 4% of the total lithium inventory has been predicted to be spilled along with a rapid loss of pressure in the loop; and (2) failure in QT for the Quench Tank in which case 600 kg of lithium is predicted to be spilled and the time required to solidify LL is predicted to be 47950s.

F. Tabares presented online a contributed paper, entitled 'Studies of thermal sputtering and vapor shielding of tin-CPS targets in the OLMAT facility.' Presented in this paper are the results of commissioning experiments of the OLMAT facility, including thermal sputtering and its associated vapor shielding measurements done for tin, which is believed to be a candidate material for the CPS-type divertor to be installed in the European DEMO reactor. For the OLMAT facility, the pulse-operating neutral beam built for TJ-II has been used as a plasma gun for divertor materials tests. The question is whether or not it is possible to identify any signs of thermal sputtering and its associated vapor shielding effects. Erosion data taken for tin in the OLMAT facility have been analyzed in detail to determine the parameters for the ad-atom model equation. Using these parameters thus obtained, further analysis has been done to see if there are any signs of vapor shielding effects. Unfortunately, the presentation time runs out before this can be concluded, and consequently, there was no time for Q&A available, although in the conclusion viewgraph shown at the last moment it is mentioned that the onset of vapor shielding has been observed at around 1600 K.

D. Raspisarda of CIEMAT, Spain, presented online a contributed paper, entitled 'The liquid metals laboratory for fusion applications at CIEMAT.' In this paper, the present status of the Liquid Metals Laboratory has been reviewed, including studies on breeding blanket liquid metals such as PbLi in terms of its chemical compatibility with reduced activation steel alloys such as Eurofer and F82H at elevated temperatures up to 550 °C and at flow velocities around 1 m s^{-1}. Also, chemical corrosion tests are being done for these alloys in static liquid PbLi. Tritium extraction and permeation experiments are also conducted for PbLi at temperatures between 300 ºC and 500 °C, and at a flow rate up to 1 m s^{-1}. For extraction tests of hydrogen isotopes, they are first injected into PbLi by permeation through niobium. Along with these ongoing experiments, a hydrogen isotope sensor has been under development, based on the permeation technique. In addition to all these activities, supporting experiments for the IFMIF-DONES facility have been conducted to develop a dedicated lithium purification loop with hot and cold chemical traps, the performance characterization of which are being conducted.

A. de Castro for E. Oyarzábal, both of CIEMAT, Spain, presented in person a contributed talk, entitled 'Comparative study of different Sn wetted W CPSs exposed to NBI fluxes in the OLMAT facility.' In this paper, the behavior of droplet formation is compared for several tungsten CPS substrates different in structure: 1. W-mesh overlaid substrates, each with a thickness of about 0.25 mm and pore sizes around 50 μm, provided by CIEMAT; 2. W-felt substrates with a thickness of 3 mm, provided by ENEA, Frascati; 3. Sintered W substrates with a thickness of 3 mm and pore sizes around 1 μm, provided by DIFFER; and 4. 3D-printed W substrates with a thickness of 17 mm and pore sizes around 100 μm, provided also by DIFFER. Essentially all of these W-substrates have exhibited inhomogeneity in wetting characteristics with liquid tin, leading to the formation of droplets found on the plasma-facing surface, mostly at the bottom of it, suggestive of the gravity effect. This clearly indicates insufficient capillary wetting of liquid tin with micro pores in the tungsten substrates. Also, it has been found that the maximum surface temperature reached after 150 ms plasma bombardment appears to depend on the bulk structure and maybe the body density as well, resulting in distinct heat transfer capacities, which might have affected the capillary wetting characteristics of liquid tin.

Session 6 on liquid metal experiments and modeling II, chaired by T. W. Morgan of DIFFER, the Netherlands.

Presented in this session were eight contributed papers on liquid metal experiments and modeling.

F. Saenz of Princeton University, the USA, presented online a contributed paper, entitled '3D-MHD Liquid-metal-flow simulations and experiments in Oroshhi-2/NIFS and LMX-U/PPPL for divertor applications.' This presentation gave an overview of several liquid metal open-flow experiments, and modeling carried out at Koleman's laboratory. Modeling using the OpenFOAM MHD code has demonstrated good agreement with the observed effects of MHD drag in a flowing liquid metal system. This MHD drag can be counteracted with external currents, however, fringing currents have been found to occur, resulting in unwanted instabilities in the flow. Also, a new concept called "divertorlets" is proposed, a divertor-like structure consisting of conducting "ladders" around the steps of which a liquid metal is circulated by $\mathbf{J} \times \mathbf{B}$-force. Unfortunately, however, time ran out for the conclusion part of this presentation.

S. Islam of Oak Ridge National Laboratory, the USA, presented online a contributed paper, entitled 'Modelling of fast flow liquid lithium divertor for a fusion nuclear science facility (FNSF) by SOLPS-ITER.' In this work, SOLPS-ITER is used to model the effect of Li or Ne impurity on the pedestal density and heat flux to the divertor surface in FNSF. Results indicate that Ne seeding is effective in reducing the divertor heat load, but it has also a detrimental effect on the upstream plasma confinement, which could then lower the fusion power output. On the other hand, lithium has been found to reduce the peak divertor heat load without affecting the upstream Z_{eff} or plasma pressure, but at the cost of high core concentration of Li^{3+} in the whole plasma volume. Additionally, the core and SOL radiation may be predicted to be much smaller with Li than that with Ne.

A. Khodak of PPPL, the USA, presented in person a contributed paper, entitled 'Development of LL PFCs using porous media and MHD drive.' This paper describes recent modeling work on the MHD-driven flow of a liquid metal underneath a CPS-type porous divertor plate, using the ANSYS CFX code. Results indicate that at flow rates above $\sim$2.0 m s^{-1} the temperature of lithium can be kept below the critical temperature of 450 °C where the evaporation rate is often observed to increase exponentially. Such a system has been evaluated as an evaporator for the Li vapor-box divertor design to be implemented in NSTX-U. Additionally, the coupling of the ANSYS code with SOLPS-ITER was discussed, which would enable the interaction of the flowing system and the plasma to be modeled with higher fidelity.

E. Emdee of PPPL, the USA, presented an online contributed paper entitled 'Modeling a lithium vapor box divertor and resulting ion flows in NSTX-U using SOLPS.' This study is closely related to the previous one in that the SOLPS-ITER code is used in both studies to model the vapor-box concept for NSTX-U. Interestingly, from the latest modeling, one can go without baffling structure in the vapor box concept for the confinement of lithium if deuterium gas puffing is done from the Private Flux Region (PFR) rather than from the Common Flux Region (CFR). In terms of reducing the heat flux to the target, however, the opposite is the case: deuterium gas puffing from CFR has turned out to be more effective than that from PFR. The conclusion may be that a combination of PFR and CFR deuterium gas puffing may be the best of both worlds.

G. Nallo of Politecnico di Torino, Italy presented in person a contributed paper, entitled 'Towards integrated target-SOL-core plasma simulations for power exhaust in the EU DEMO with a liquid metal divertor.' Modeling work in this study has been done, using the parameters obtained from the laboratory experiments in a linear plasma facility: Magnum-PSI. Then, modeling with SOLPS-ITER code has been done, coupled with a self-consistent finite element method model in order to simulate the effect of Sn and Li divertors on the plasma performance in the EU-DEMO. Results indicate that the combination of argon seeding with either Sn or Li could provide a wide operational window for the EU-DEMO, enabling the operation even at relatively low separatrix densities. Further the SOLPS-ITER code is now being coupled with the core ASTRA-STRAHL code for the full core to wall modeling of the liquid metal influence on the plasma.

G. Zuo of ASIPP, China, presented online a contributed paper, entitled 'Fuel particle control using different Li technologies in EAST.' This paper gives an overview of various lithium-applied systems used in EAST to improve plasma performance, including the lithium granule injector, lithium aerosol injector, and FLiLi. The EAST team have been able to demonstrate high performance long-pulse discharges with Li coatings combined with continuous Li powder injection. The next step may be to produce a real-time feedback control system for Li powder injection to regulate the wall recycling effect on plasma performance.

K. Sasaki of Hokkaido University, Japan presented in person a contributed paper, entitled 'Ejection of droplets from liquid gallium by the collapse of bubbles induced by plasma-liquid interaction.' This experimental study employs an RF-plasma source to investigate the behavior of bubbles formation and bursting with liquid gallium. As has been observed with other liquids, after a certain period of plasma exposure, the formation of bubbles occurs and then droplets are ejected upon bursting of these bubbles. The frequency of bursting has been found to increase generally with increasing ion implantation flux, fluence, and liquid temperature. It is rather interesting, but not fully understood why much fewer droplets have been observed under the exposure to He-plasmas than for H-plasmas, which warrants future work.

B. Chuilon of UKAEA, the UK, presented in person a contributed paper, entitled 'Concept design study of a liquid metal supply system for divertor targets.' Clearly, this work has been motivated by the need for designing a liquid tin supply loop system for a CPS-type divertor to be used in a spherical tokamak power plant such as STEP. The development of a CPS system must be done, based on all the lessons learned from industrial experience, particularly about the chemistry of tin and its compounds, affecting the compatibility with the structural materials in contact. The gravity must be used cleverly in order that the liquid circulation speed can readily be regulated; 1. the melt tank to be set at the highest point; 2. the storage tank to be set at the lower level, so that liquid tin can be gravity-fed; and 3. the dump tank to be set at the lowest level. Also, only high technological-readiness-level components must be used, making the design lower risk and more feasible for maintenance. Additionally, a risk assessment, and mitigation strategies are proposed, identifying in particular corrosion and leak detection as the largest challenges for the system.

Session 7 on divertor physics and heat flux mitigation, chaired by M. Shimada of FMR QST, Japan.

Presented in this session were five contributed papers on divertor physics and heat flux mitigation.

A. Shone of Univ. of Illinois, the USA, presented in person a contributed paper, entitled 'Retention Induced by Lithium Evaporation in HIDRA.' The HIDRA facility for Hybrid Illinois Device for Research and Applications, at the University of Illinois Urbana-Champaign, is a tokamak-stellarator hybrid (l = 2, m = 5) device, capable of long-pulse operation up to 3600 s. In recent studies of HIDRA helium plasmas (600 s pulse length, 1sccm He flow rate), the HIDRA-MAT facility has been utilized for in-situ evaporation of $\sim$100 mg of LL into the plasma edge with a tungsten substrate exposed. These in-situ lithium evaporation shots have exhibited "co-deposition" effects, leading to an 85% reduction in helium concentration in the plasma, despite a constant flow rate of helium throughout a 600 s pulse. From the observations of LEEX for the Lithium Evaporation Experiment shots, it is hypothesized that 100 μg of pure lithium could cause this retention effect in HIDRA.

B. Liu of Dalian University of Technology, China, presented online a contributed paper, entitled 'Impacts of lithium injection positions on lithium transport and heat load on EAST with EMC3-EIRENE modelling.' Presented in this paper are the results from EMC3-EIRENE computations performed to investigate the transport behavior of low-recycling Li injected from several poloidal positions and its impact on the resultant heat flux distribution. Detailed analysis of Li spatial amount, power exhaust and heat load has been carried out for different upstream electron densities. It has been found that low-recycling Li impurity injections near the strike points can result in the toroidal asymmetry in the heat load and high-recycling impurity distributions.

M. Ono of PPPL, the USA, presented in person a contributed paper, entitled 'Active lithium injection for a real time control of the divertor heat flux for fusion devices.' The application of lithium in NSTX resulted in moderating the divertor surface temperature while improving the plasma confinement performance. These encouraging results from Li experiments and related modeling calculations have led to the passive and active radiative LL divertor concepts: RLLD for the Radiative LL Divertor, and ARLLD for the Active Radiative LL Divertor. The rapid radiative process is expected to spread the edge heat load localized on the divertor to the entire chamber wall surfaces, thereby facilitating divertor heat load mitigation with relatively small amount of lithium ($\sim$ few moles s^{-1}) to handle the expected steady-state high divertor heat load. Recent data indicate that the transient heat load can be controlled with lithium injection done at the right time. It is also suggested that lithium encapsulated in a plastic shell can be used to deliver lithium to where it is needed most. Explored in the present work were more details on the actual implementation of lithium pellet injection and its associated lithium deposition to better control the divertor heat flux. Since the highest heat flux region is usually the target area of heat flux reduction, it is relatively straightforward to design a capsule which can deposit lithium preferentially in the high heat flux region. If the divertor PFR is available to position the lithium delivery system, it is likely to be the best location due to the short path required to reach the high heat flux regions for both sides of the divertor legs.

B.A. Pint of Oak Ridge National Laboratory, the USA, presented in person a contributed paper, entitled 'Liquid metal compatibility assessments for Sn, Li and Pb-Li.' Several liquid metals have been investigated for the blanket and PFC applications. For PFC applications, tin is lower than lithium in vapor pressure, but has shown poor compatibility with FK2H (Fe-8wt.%Cr-2W) in the static capsule testing done at 400 °C. Pre-oxidized APMT (Fe-20Cr-5Al-3Mo) alloy has demonstrated more promising results when it is in contact with static tin at temperatures between 400 °C–500 °C. So, a Thermal Convection Loop made of APMT has been tested in contact with flowing tin for 1000 h with a peak temperature of 400 °C. However, large mass losses have been observed for pre-oxidized Oxide Dispersion Strengthened (ODS) with the composition of Fe-(10–12) Cr-6AI and APMT alloys, suggesting that tin cannot be recommended for the PFC applications. For lithium, however, Liquid Metal Embrittlement tests conducted for F82H after annealed at 500 °C for 500 h indicate no embrittlement. Also, essentially no mass loss has been observed for F82H in contact with lithium at 600 °C, whereas under the identical conditions orders of magnitude larger mass losses have been observed with tin at 400 °C. These data indicate that liquid tin cannot be recommended as the coolant for PFCs either.

O. Bond of University of Oxford, the UK, presented in person a contributed paper, entitled 'Generalizing the geometry of liquid metal infused trenches (LiMIT).' Used in this work are the asymptotic analysis for equation-based modeling with COMSOL to describe mathematically the LiMIT divertor concept, pioneered by the engineering department at UIUC. Using asymptotic approximations for the key bulk features of lithium flows along a trench in the limit of large Hartmann number, the flow behavior has been shown to depend on the physical properties and geometry of the trench. They have quantified the crucial difference between the observed velocity at the free surface and the actual velocity within the trenches. Geometric parameter scans have been done to obtain steady state solutions for up to 10 MW m^{-2} power handling. Finally, it has been explored whether beneficial flow properties can be obtained, using non-rectangular cross-section trenches.

Session 8 on plasma-liquid metal interactions, chaired by R. Maingi of PPPL, the US.

In this session, there are one invited paper and five contributed papers on plasma—liquid metal interactions.

M. Morbey of DIFFER, the Netherlands, presented in person an invited talk, entitled 'Deuterium retention in Li-D co-deposits in Magnum-PSI and comparison with SOLPS-ITER,' reporting on the deuterium plasma bombardment experiments on lithium conducted in the Magnum-PSI linear plasma device, simulating the vapor box situation. Deuterium retention in lithium measured simultaneously with EBS for Elastic Backscattering Spectroscopy and NRA for Nuclear Reaction Analysis have been modeled with the SOLPS-ITER code. Examining the temperature dependence, deuterium retention in Li is found to remain relatively high, essentially keeping the LiH composition, at temperatures up to 400 °C at which point rather fast desorption starts to empty host lithium.

L. Li of ASIPP, China, presented online a contributed talk, entitled 'Effect of air contamination on deuterium desorption in LL.' One of the key questions being examined was what effect non-metallic impurities such as oxygen and nitrogen in the air would have on H retention and release from Li. Lithium in one chamber was exposed to different gases at 400 °C, and then heated in a second chamber up to 600 °C for thermal desorption spectroscopy. It has been found that the concentration ratio of non-metal impurities to D_2 is important in determining the desorption temperature of D_2. Also, the desorption temperature of D_2 has been found to sensitively change with the pressure of water vapor pre-absorbed on the surface of Li. Finally, these non-metallic impurity gases are found to make a weak impact on D_2 desorption behavior, but did affect the solubility of deuterium more profoundly.

K. Tamura of Nagoya University, Japan, presented in person a contributed talk, entitled 'Quantitative evaluation of hydrogen accumulation into bubble occurred in liquidized Sn-Bi-Li-Er under H_2 plasma exposure,' reporting on the bubbling behavior of a liquid metal alloy, composed of 42at%Sn, 31at%Bi and 25at%Li under H-plasma bombardment. Bubble formation has been observed more often and the bubble diameter becomes larger as the hydrogen ion implantation flux increases. Interestingly, the elemental composition of the droplets ejected along with the exfoliation of bubbles has been found to be strongly dominated by Li, which might suggest little solubility in the liquid metal alloy of Li.

E. Carella of CIEMAT, Spain, presented online a contributed talk, entitled 'Coating compatibility with lead lithium and Li diffusion measurements,' reporting on the chemical compatibility experiments done on the water-cooled Pb-Li breeder blanket design, employing a reduced activation steel alloy: EUROFER as the structural material, and alumina coatings as the tritium permeation barrier. As can be expected from the thermodynamic data (Ellingham diagram), serious corrosion occurs at elevated temperatures, which has been observed with SIMS, NRA and RBS analysis such that lithium penetrates deeply into the alumina essentially throughout the coatings thickness. One proposed resolution for the chemical compatibility issue may be to spread tungsten powder over alumina coatings, the evaluation of which, however, requires a whole new set of experiments.

J. Patiño of CIEMAT, Spain, presented online a contributed talk, entitled 'Design of an electrochemical sensor for on-line detection of hydrogen isotopes (H, D and T) on liquid metals.' Electrochemical sensors have been developed to be used for a variety of applications, e.g. biological testing, in a wide range of requirements/environments. Sensors for fusion applications are in an early stage of R&D, such that final tests of the first generation are expected in summer 2023. It has been found to be difficult to find materials compatible with liquid metals such as lithium. Possible compatible materials with LL may include V, Nb, Y, and Ta.

B. Garcinuño of CIEMAT, Spain, presented online a contributed talk, entitled 'H-isotopes extraction from liquid PbLi using Permeation Against Vacuum (PAV): permeable membrane vs. free-surface.' In the PAV concept, tritium dissolved in PbLi is extracted via permeation by the pressure difference imposed on the outer side of the surrounding membrane. This procedure, in principle, should extract tritium from PbLi, facilitating efficient fuel management in a fusion reactor. The requirements for the membrane material include: (1) chemical compatibility with PbLi, (2) ability to withstand elevated temperatures up to $\sim$550 °C, and (3) high permeability by tritium. A dedicated PbLi-loop facility for tritium extraction experiments has been put together to evaluate candidate membrane materials. First results are expected in time for the next ISLA meeting in 2024.

Session 9 on liquid metal PFCs, erosions and wettability, chaired by T. Goto of NIFS, Japan.

Presented in this session were six contributed papers on liquid metal PFCs, erosion and wettability.

As the first speaker of the session, B. Wynne of Princeton Univ., the USA, presented in person a contributed paper, entitled 'In-situ hydride separation and magnetic field gradients on LMX-U for LMD applications.' This paper focuses on two separate but mutually related subjects: (1) the gradient magnetic field effect on the behavior of a liquid metal flow; and (2) lithium hydride separation using a magnetic centrifuge. Regarding (1), experimental and simulation results are described under the LMX-U conditions, where the transverse magnetic field changes in the direction of a liquid metal flow. Simulation results using the COMSOL Multiphysics Program have indicated that the grad-**B** force can be greater than the gravity force in a reactor condition. Regarding (2), the concept of magnetic centrifuge, which is a combined approach of the classic centrifuge system and the hydro cyclone using the $\mathbf{J} \times \mathbf{B}$ force induced by the externally applied current has been shown. Simulations by COMSOL have indicates the possibility of the separation of lithium-hydride from LL. These data warrant further experimental and modeling work in the future.

X.C. Meng of the Institute of Energy, China, presented online a contributed paper, entitled 'Corrosion characteristics of different fusion materials in LL.' This paper describes the corrosion behavior of several steel alloys, TZM, molybdenum and copper in contact with static LL at temperatures of 70, 300 and 400 °C. These steel alloys include: 304 stainless steel (304 SS), 316L stainless steel (316L SS), Chinese Reduced Activation Ferritic/Martensitic steel (RAFM) CLF-1, ODS-RAFM. Generally, steel alloy specimens tend to exhibit non-uniform corrosion due to preferential dissolution and grain boundary attacks by chemical reaction. Weight losses have been observed for Mo and TZM in LL. Observed for TZM is grain boundary corrosion due to the selective dissolution of carbon, titanium and zirconium. In comparison with these alloys, copper has exhibited severe corrosion, due to well-known intermetallics formation with LL. In summary, the physico-chemical compatibility with LL may be in order from the best to the worst appears ODS-RAFM > Mo > CLF-1 > TZM > 316L SS > 304 SS > Cu.

X.C. Meng also presented online for D.H. Zhang of ASIPP, China, a contributed paper on the same subject, entitled 'Corrosion characteristics of China RAFM steel of CLF-1 in static LL,' describing the corrosion behavior of a Chinese reduced activation steel alloy: CLF-1 in contact with static LL at 600 and 820 K. Despite the noticeable depletion of iron and chromium near the surface after the exposure for 528 h, no significant change in tensile strength has been observed. It was also found that the content of nickel and manganese, which came from the SS304 crucible, increased after the exposure. Therefore, planned in the future are additional experiments, using a crucible made of corrosion-resistant materials.

C. López Pérez of Penn State Univ., the USA, presented in person a contributed paper entitled 'Liquid Li wettability on W and hydrogen dynamics in hybrid liquid Li-W substrate,' presenting, for the first time, the data on real-time observations of the capillary wetting behavior of LL droplets on porous tungsten substrates made for the CPS application, fabricated by the spark plasma sintering technique. These tungsten substrates are first irradiated by helium at room temperature with different fluence (9×10^{13} cm^{-2} and 7×10^{16} cm^{-2}) for surface cleaning and then small amounts of LL were carefully poured onto the surface of a porous tungsten substrate so as to form a droplet, using the in-vacuo LL dropper system as part of the IGNIS facility for Ion-Gas-Neutral Interactions with Surface. Observations have indicated that some of the LL droplets are absorbed successfully into the micro pores of tungsten, but the rest appear to be damaged during percolation, presumably due to the lithium oxide film formation by oxygen-containing residual gases and its fracture. Although the details need to be further investigated, there appears to be a trend that tungsten samples subjected to higher He irradiation fluences exhibit more LL droplet fractures.

J. Cecrdle of Czech Academy of Science, Czech, presented in person a contributed paper, entitled 'HeatLMD code for liquid metal plasma facing component erosion modelling.' This paper describes the current status of the HeatLMD code, a time dependent computer code, developed for the calculation of overall liquid metal erosion, taking into account the processes: erosion (sputtering, thermal erosion, evaporation), prompt redeposition and vapor cooling for radiative losses. It is designed to take direct inputs from diagnostics. Benchmarking against the data from lithium vapor shielding experiments done at the MAGNUM-PSI linear device has been done. The code will be utilized for modeling and analysis of LMD performances in several devices, including COMPASS, COMPASS-U, AUG and OLMAT.

S. Krat of National Research Nuclear Univ., Russia, presented online a contributed paper, entitled 'Composite Lithium-boron material as a candidate for plasma facing elements.' The possible use of Lithium-Boron Composites (LBC) in the form of Li_7B_6 or Li_5B_4 matrix filled with LL as a plasma-facing material is discussed in this paper. Electron beam and helium plasma irradiation experiments with heat fluxes of more than 1 MW m^{-2} have been conducted on these LBC composites, which survived for 1.5 h without cooling and no droplet emission. The CPS-like characteristics have been observed in which lithium migrates to hot regions. Sputtering of the lithium boride matrix has been observed, but no structural deformation occurs until lithium has completely been dried out. Hydrogen plasma irradiation and testing in a small tokamak device are currently being planned.

3. Conclusion

During Session-10, the closing session, technical session summaries were presented by the respective session chairs. There was also an intense discussion on the next symposium, ISLA-8, as to when and where it should be held. The final agreement is that ISLA-8 shall be held in the fall of 2024 in China if the COVID-19 situation has been resolved by then, otherwise it will be held in the Netherlands. The decision on the host location will be made towards the end of 2023.

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