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Testing of Liquid-Sn Divertor Prototype: IPP Contribution

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This work has been carried out within the framework of the EUROfusion Consortium and has received funding from the Euratom research and training programme 2014-2018 and 2019-2020 under grant agreement No 633053. The views and opinions expressed herein do not necessarily reflect those of the European Commission.

Introduction

- **Goal: Test liquid-Sn divertor component prototype in high-power tokamak**
  - ➢ Divertor manipulator of ASDEX Upgrade

- **Necessary preparatory groundwork**
  - ➢ Establish boundary conditions for successful testing of liquid-Sn component in ASDEX Upgrade
  - ➢ Design suitable prototype sample
    - ↳ In collaboration with TU/e and DIFFER
  - ➢ High heat flux testing of component in GLADIS testbed (IPP)
  - ➢ Design suitable ASDEX Upgrade discharge

- **Actual ASDEX Upgrade tests will be part of IPP internal experiment programme**
  - ➢ Envisioned: Summer 2022, in last days **before extended maintenance opening (!)** of ASDEX Upgrade
  - ➢ No EUROfusion budget allocated for this

Boundary conditions for ASDEX Upgrade experiment

- **Overall constraint: Ensure machine safety and avoid permanent Sn inventory in AUG**
  - Liquid metal experiments must not have long-term influence on main ASDEX Upgrade programme
  - Limited possibilities to remove Sn deposits from remote areas
    - E.g., tile gaps, sub-divertor region, ducts/ports
    - No widespread use of aggressive chemicals (e.g., HCl) possible
    - Will mainly have to rely on cleaning discharges → can Sn chemical erosion [1] help?

- **Critically review available data on Sn erosion behaviour**
  - Lab experiments (e.g. IPP [1], DIFFER [2], ENEA [3])
    - Possible/observed mechanisms: evaporation, sputtering, droplet ejection, chemical erosion
  - Tokamak experiments (e.g., Loureiro [4], Mazzitelli [5], Compass? [6])
  - Complete gaps with pinpoint experiments if necessary

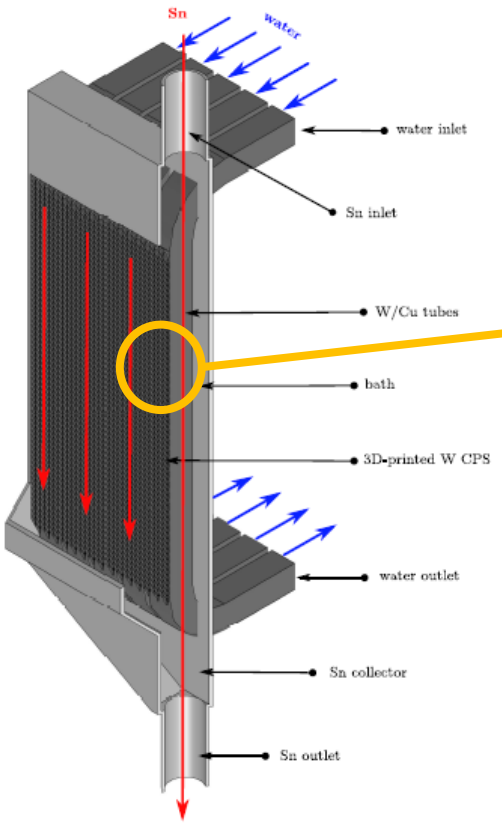
[1] A. Manhard et al, *Nucl. Fusion* **60** (2020) 106007
[2] W. Ou et al., Nucl. Fusion 60 (2020) 026008
[3] A. Cremona et al, Nucl. Mater. Energy **17** (2018) 253-258
[4] J.P.S. Loureiro et al., *Nucl. Mater. Energy* **12** (2017) 709–713
[5] G. Mazzitelli et al, *Nucl. Fusion* **59** (2019) 096004
[6] J. Horacek et al., J. Nucl Mater. **25** (2020) 100860 *(note: Li / LiSn)*

Boundary conditions for ASDEX Upgrade experiment

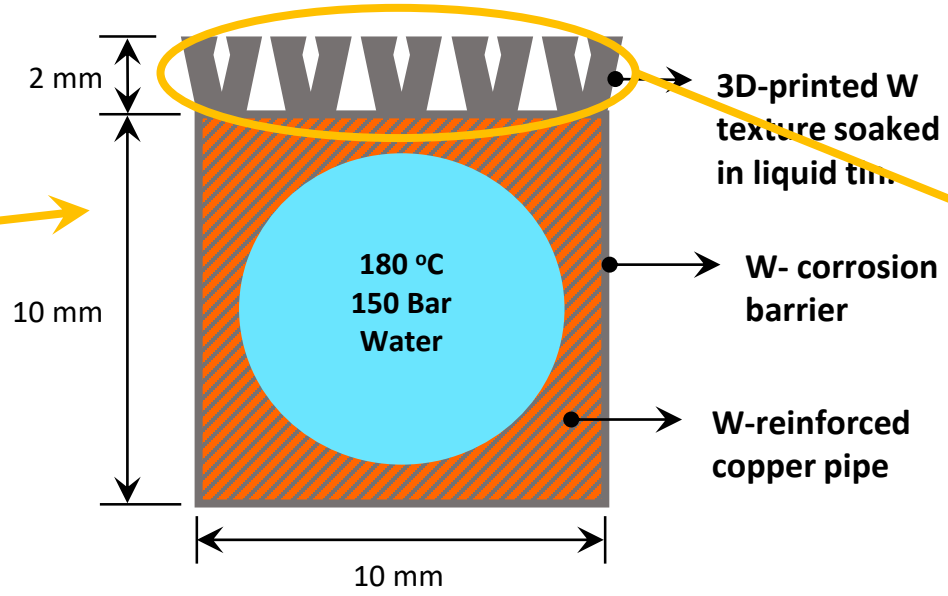
- **Overall constraint: Ensure machine safety and avoid permanent Sn inventory in AUG**
- **Critically review available data on Sn erosion behaviour**
- **Set limits for acceptable release of Sn into ASDEX Upgrade vessel**
  - In close collaboration with ASDEX Upgrade experts
  - Draw on large knowledge base for experiments with high-Z impurities (W)
- **Identify suitable diagnostics to monitor Sn release**
  - Interface with teams of previous L-Sn experiments in Tokamak environments
- **Possible time slot: at end of campaing in Summer 2022**
  - Afterwards: ~ 1 year break for extended maintenance of ASDEX Upgrade
  - Prototype needs to be ready well in advance (≥ 3 months)

DEMO component design (DIFFER)

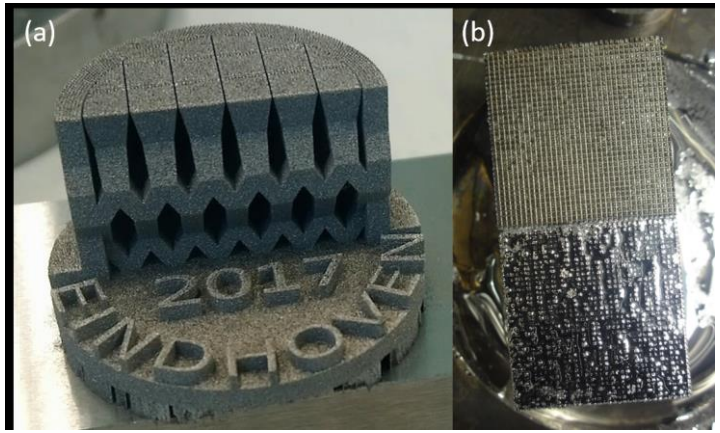
images courtesy of T.W. Morgan, P. Rindt, N.J. Lopes Cardozo, DIFFER



DIFFER component design concept for DEMO



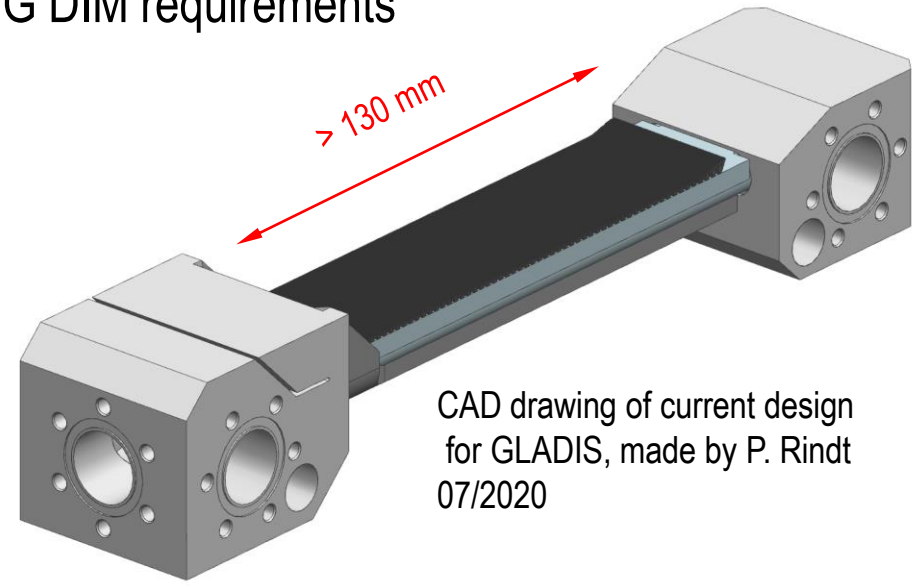
single CPS element



demonstration of additive manufacturing for W CPS

GLADIS tests prior to ASDEX Upgrade experiments

- **Aim: Evaluation of component behaviour loaded with well-defined heat flux**
  - ➢ First campaign: to evaluate the cooling structure w/o LM. Screening and cycling tests, stepwise increase of cooling-water inlet up to 230°C and heat flux up to 10-20 MW/m²
  - ➢ 2nd campaign: depending on the results of first test without Sn, a test with Sn filling could be performed in GLADIS.
    - ↳ Open question: How we can close the 2 K temperature gap to the Sn melting temperature
    - ↳ Additional electrical heating, use of commercially available alloy Sn99.3/Cu0.7, T_{melt}=227°C ?
  - ➢ 3th campaign to qualify a mock-up designed according to the AUG DIM requirements
- **Status:**
  - ➢ Development of a mock-up design adapted to GLADIS
  - ➢ *Schedule of manufacturing and HHF testing to be agreed*
- **Time constraint due to AUG schedule**
  - ➢ GLADIS tests should ideally be finished by end of 2021



CAD drawing of current design for GLADIS, made by P. Rindt 07/2020

Prototype sample for ASDEX Upgade

- **Main development and manufacturing at DIFFER and TU/e**
  - Currently in progress
  - Capillary porous system
  - Possibly by additive manufacturing

- **IPP: provide interface information for GLADIS and AUG divertor manipulator**
  - Size: presumably divertor tile insert with ~ 20x20 mm side length (Sn surface area)
  - Instrumentation: e.g. thermocouples, Langmuir probes
  - Periphery: mainly pre-heating of sample
    - Electrical heater?
    - Hot-water coolant loop? (insufficient temperature for melting Sn before discharge starts!)

Design of ASDEX Upgrade discharge

- **ASDEX Upgrade exposure envisioned for end of campaign in summer 2022**
  - ➢ Should be dedicated discharges for L-Sn component

- **Tailor set of discharges**
  - ➢ L-mode / H-mode
  - ➢ Attached / detached; gas puffing (D_2, N_2, Ne?, Ar? $\rightarrow$ Sn sputtering by impurities!)
  - ➢ Strike point position (sweep?)

- **Very important: power load on sample, energy budget**
  - ➢ Available active cooling loop for divertor manipulator cannot pre-heat above melting point of Sn
  - ➢ Probably electrical heater necessary
    - ↳ Consequence: only inertial cooling
    - ↳ Need to keep track of energy absorbed by sample!

Summary

- **DIFFER TU/e develop and manufacture liquid Sn divertor prototypes**
  - IPP provides interface information for GLADIS and ASDEX Upgrade
- **IPP: HHF testing of liquid Sn prototypes**
  - 1st campaing: dry testing of CPS component optimized for GLADIS tests
  - 2nd campaign: testing of Sn-filled CPS
  - 3rd campaign: testing of sample for ASDEX Upgrade
- **IPP: Design of ASDEX Upgrade experiments**
  - Specify boundary conditions (particularly: avoid excessive Sn release into ASDEX Upgrade!)
  - Determine optimal set of diagnostics
  - Design discharges for testing liquid Sn components
- **ASDEX Upgrade experiments: internal programme in collaboration with TU/e and DIFFER**