UK Atomic Energy Authority

LMD Review/KoM 2022

Design Activities and 2022 Tasks at CCFE

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Thursday 10th March 2022

EUROfusion

Research Councils UK Energy For a Low Carbon Future

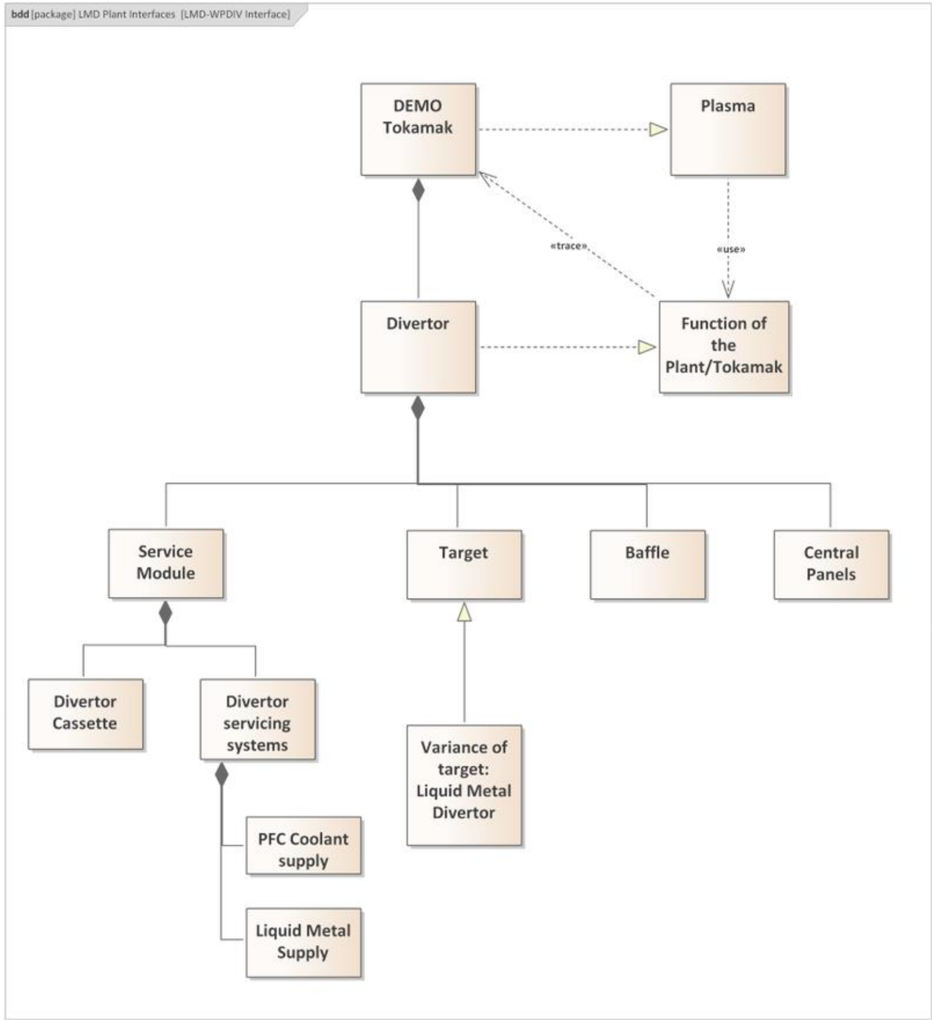
CCFE CULHAM CENTRE FOR FUSION ENERGY

This work was part funded by the RCUK Energy Programme [grant number EP/P012450/1]. 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 2019-20 under grant agreement No 633053. The views and opinions expressed herein do not necessarily reflect those of the European Commission.

Introduction

1. Systems Integration
2. DEMO Lower Port Piping Challenges
3. 2020 Divertor Baseline Design
4. Plant Integration – LM Supply Systems
5. Target Design and Proto-type Mockup
6. AWP2022 Proposed Activities

System Integration – LMD as a Subsystem



- For consideration into DEMO, LMD considered as a variance to divertor target plates
- Interfaces with:
  - Plasma
  - Tritium Fuelling and Vacuum system
  - Plasma Control System
  - Further associated systems to include:
    - Manufacturing
    - Construction
    - RM Systems
    - Plant operator systems

Current RM Operations	Time (hrs)	Days
Entering reactor lower port	82	3.4
Removing LP Ancillaries	47	2.0
Removing Divertors	12	0.5

- As LMD targets are in-vessel components it has to either conform, or have its own, DEMO RM strategy.
  - Impacts availability of system
  - An increase in RM complexity will impact commercial feasibility.
  - Simplify processes to mitigate!

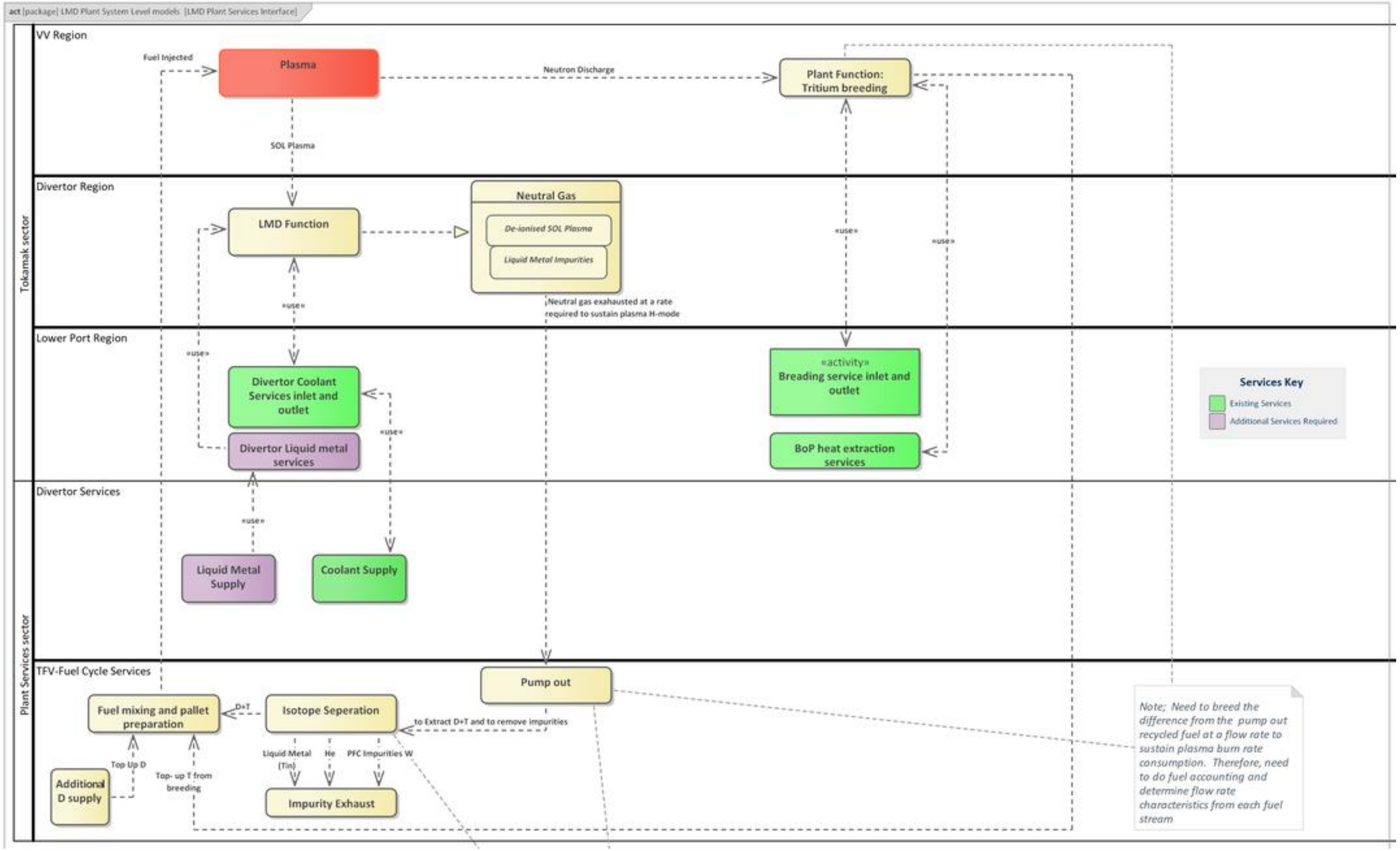
Linking DEMO Divertor Requirements to LMD

		Divertor Plant Level System Primary Function (PF)	DEMO PRD Link
1	PF 1	To remove impurities from the plasma by de-ionising the SOL plasma below the X point	PRD_11: The plasma scenario of the standard DEMO pulse shall be defined within the known stability limits with sufficient margin for controllability
2	PF 2	To prevent the back flow of neutrals into the plasma	
3	PF 3	To prevent neutral confinment regions that restrict the pump out of neutrals	
4	PF 4	To maintain integrity under plasma transient events	PRD_10: The duration of flat top shall be at least 2h
5	PF 5	To maintain integrity under a steady state magnetic profile and a steady state High Heat Flux	PRD_10: The duration of flat top shall be at least 2h

		Divertor Plant Level System Secondary Function (SF)	
6	SF 1	To enable the plasma control system to maintain the desired plasma mode by adjusting divertor heat transfer and pump out rate	PRD_11: The plasma scenario of the standard DEMO pulse shall be defined within the known stability limits with sufficient margin for controllability
7	SF 2	To pump out neutrals into the active fuel cyce of the TFV during plasma pulse as part of the recycled fuel stream	PRD_11: The plasma scenario of the standard DEMO pulse shall be defined within the known stability limits with sufficient margin for controllability TFV Link Here for recycling loop as well
8	SF 3	To enable the maintenance of the divertor region in accordance to DEMO maintenance strategies	PRD 06: DEMO shall demonstrate the reliable operation of the plasma including a low number of required unplanned maintenance intervals to repair damaged components due to failures triggered by off-normal plasma events PRD_09: DEMO shall allow for regular removal of consumables for the purpose of in-service inspection and technology qualification
9	SF 4	To enable the manufacturing, handling and integration of the divertor to within feasible parameters	PRD_02: The DEMO capital cost shall be minimized PRD_07: The DEMO plant architecture as well as critical technologies and materials shall be applicable in a FPP without significant change
10	SF 5	To enable the divertor to be decommissioned and disposed to within feasible parameters	PRD_23: he DEMO plant shall be designed for an acceptable decommissioning cost and duration

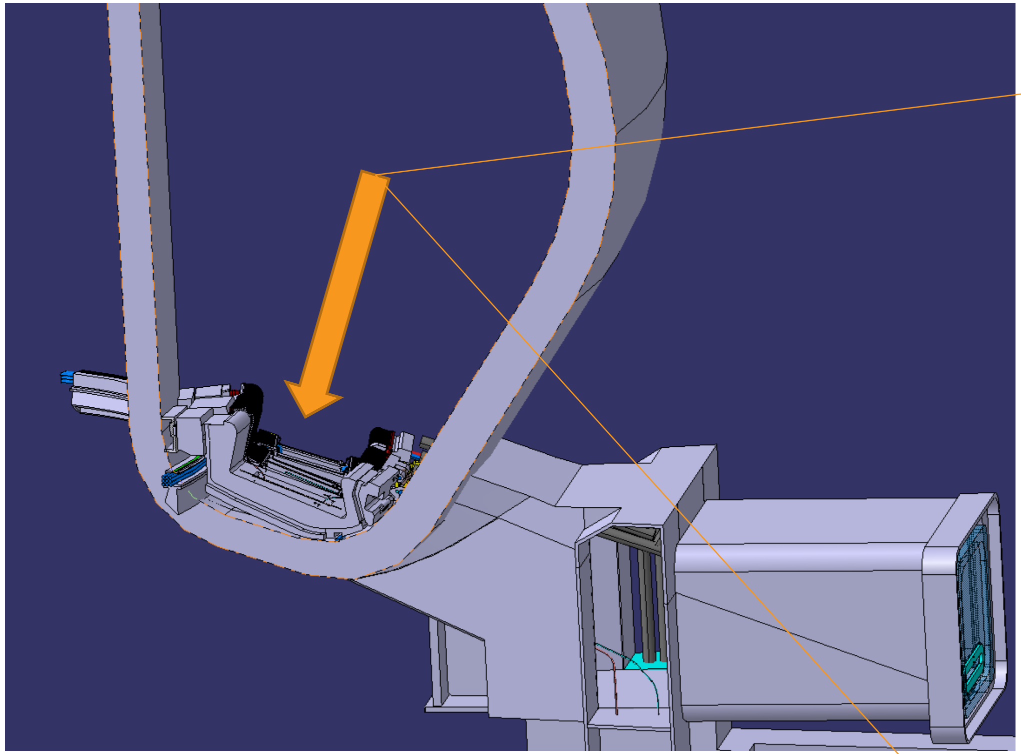
		Divertor Plant Level enviromental functions (As part of system qualification) EF	
11	EF 1	To provide neutronic shielding to components behind the divertor	PRD_22: The DEMO plant shall minimise dose rates in all manned areas in accordance with the ALARA principle.

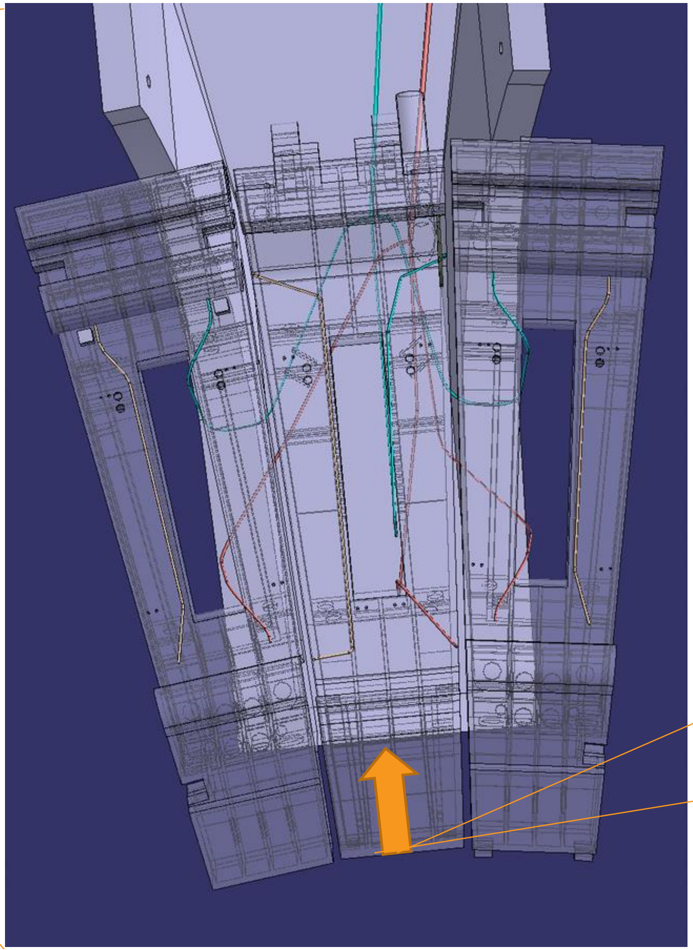
System Integration – T Fuelling and Vacuum

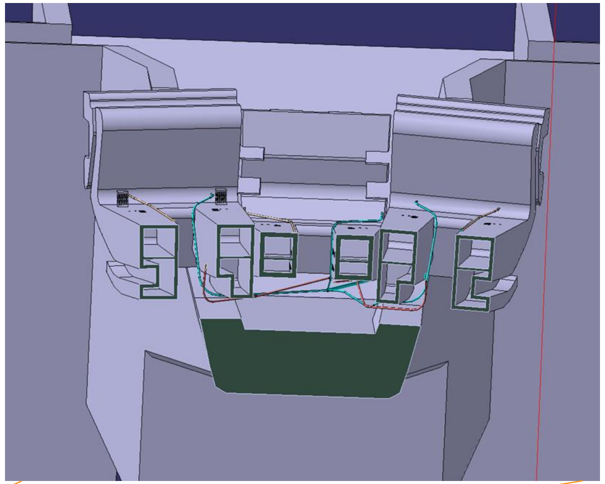


- Closed loop fuel system proposed by WPTFV
- Extracts D and T from the neutrals in exhaust stream
- Sn impurities added to neutral gas increases difficulty in TFV isotope separation
- To be done in real time, will likely increase system latency

DEMO Lower Port Piping Challenges

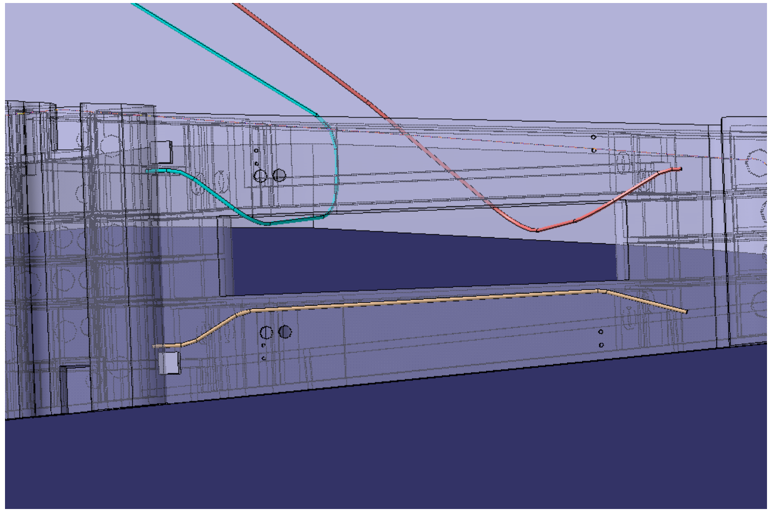


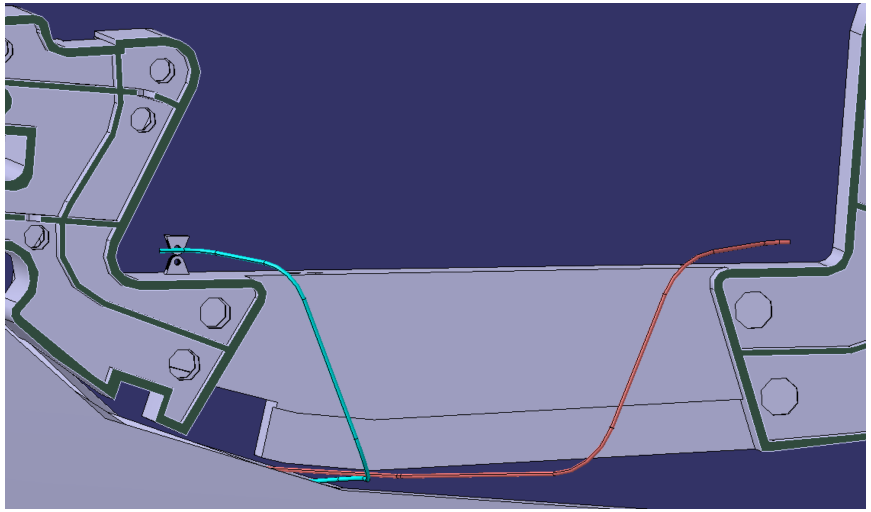




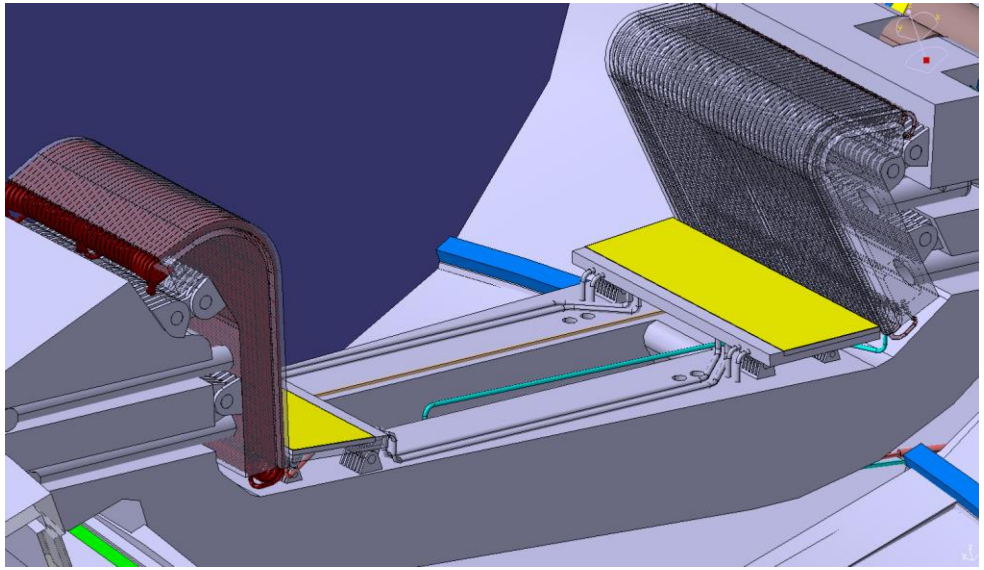
- 1” Pipe connection for Sector
- ½” Pipe connection for each cassette
- Pipe material SS316L SCH40S
- Corrosion allowance not considered (yet)

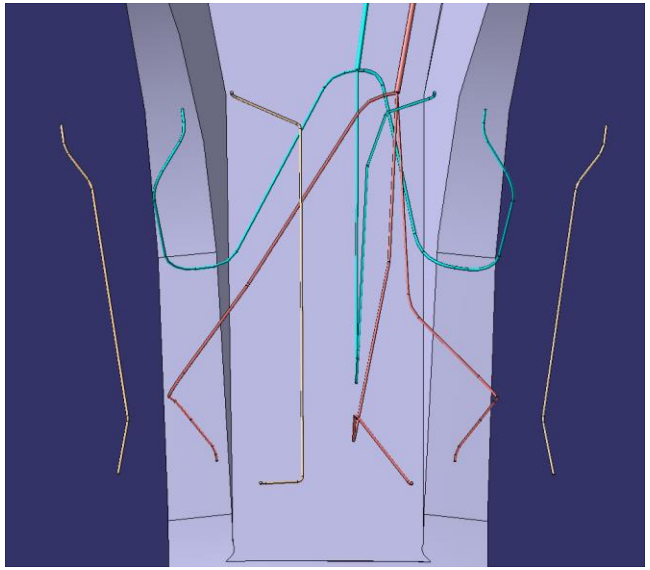
DEMO Cassette Piping Challenges



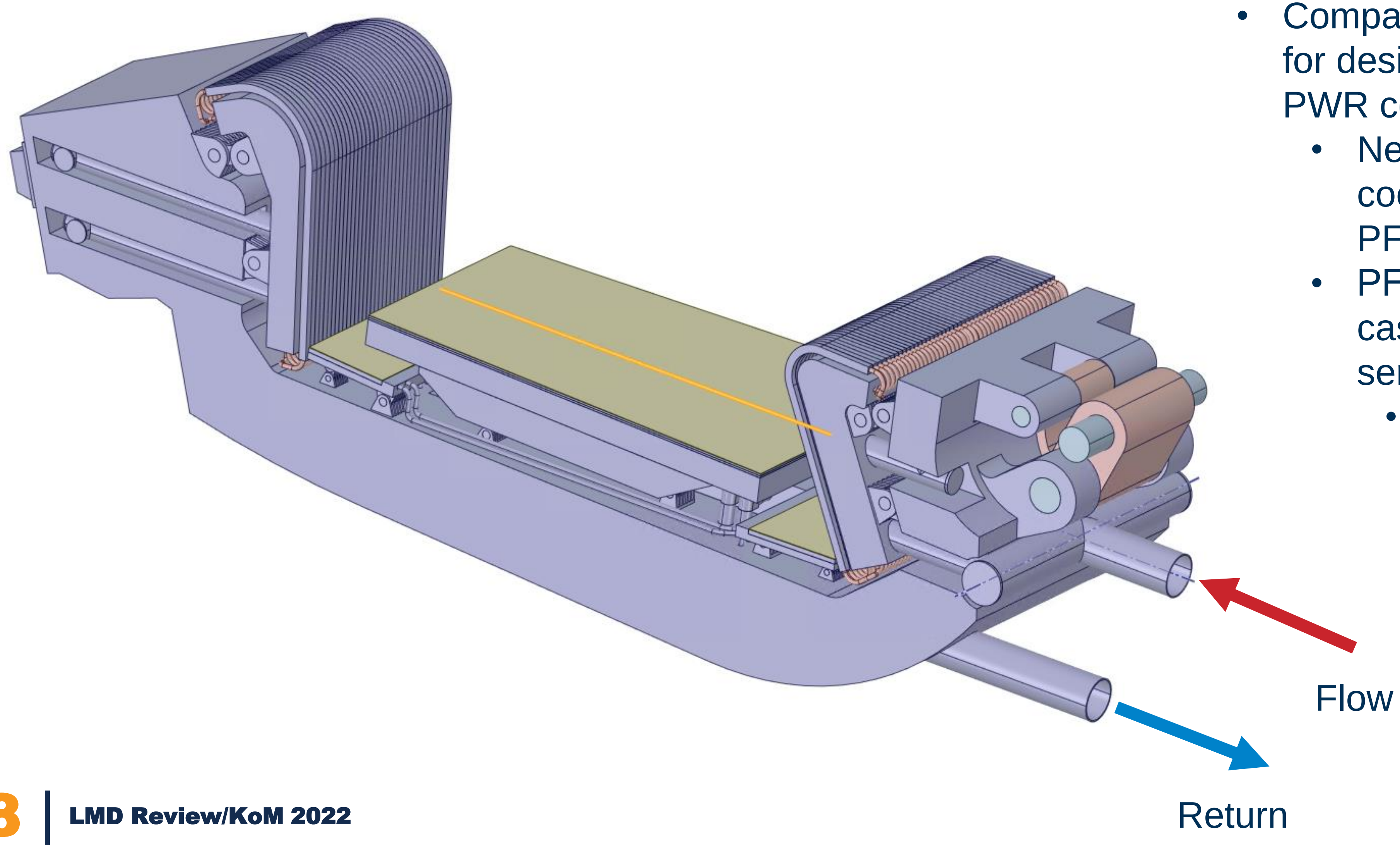


- Piping to be routed through cassette vacuum port for protection against neutrons
- Assumed LM flow and return connections at target lower edge
    - Interface issues with PFC coolant diffuser
- Targets connected in series to simply MHD pressure in-balance (TBC)





Changes to Divertor Baseline Design 2021 Baseline



- Compatibility issue foreseen for designs that use coolant at PWR conditions.
  - New baseline has single coolant supply for both PFC and Cassette.
  - PFC's cooled first, then cassette connected in series.
    - Cassette body will likely require significant modification to withstand pressures of 155 bar.

Integration – LM Supply for DEMO

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Purpose of Integration Study for Liquid Metal Divertor Supply System (LMDSS):

- Review of LM handling technologies
- Assessment of LM supply options
  - Static reservoir
  - Recirculating loop
- Generation of a concept LMDSS.
  - Hazard identification and mitigation.
  - Key component specification/recommendation
  - Additional work

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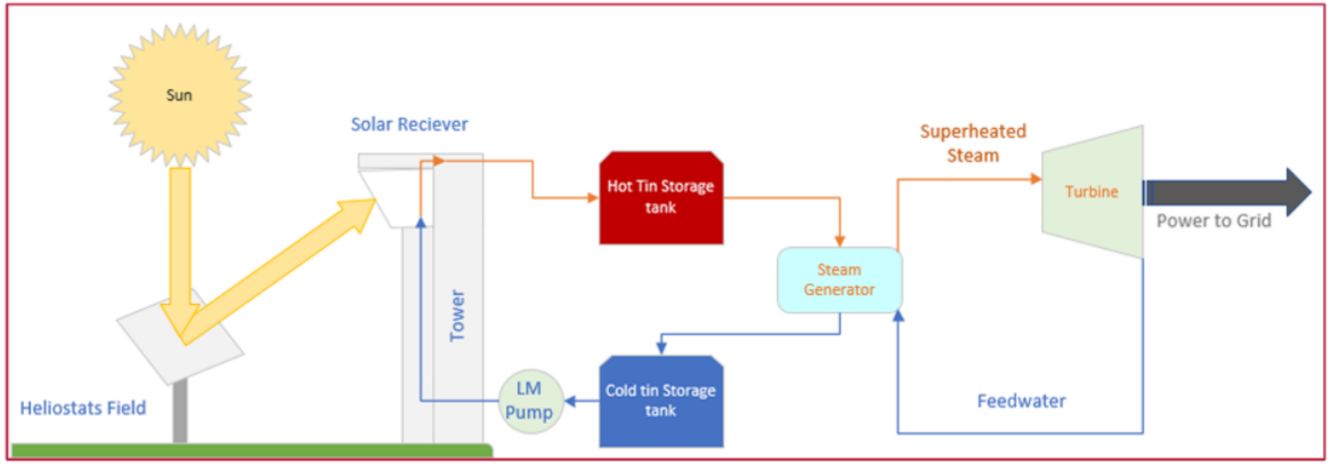
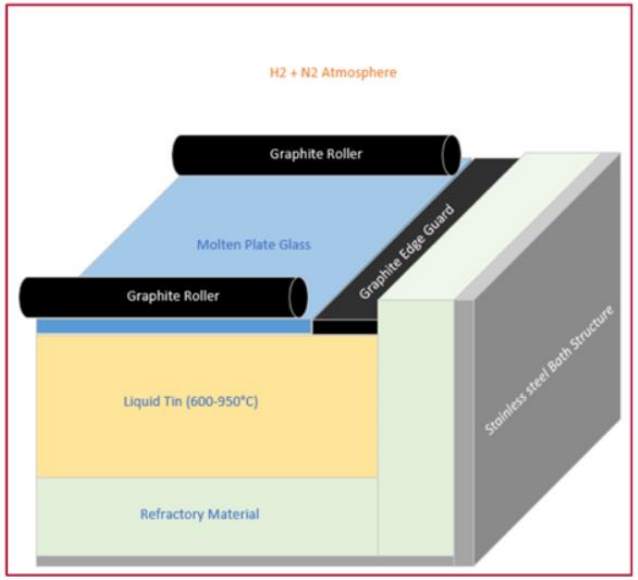
Review of Existing Sn Handling Methods

Industry Experience of Liquid Tin Handling:

- Pilkington Float Glass production
    - Glass poured and rolled on liquid Tin to get flat glass sheets.
    - Refractory material, storage tub
    - Linear displacement pumps to circulate Tin slowly.
    - Reductive atmospheres used to prevent oxide formation
- Concentrated Solar Power
    - Tin used as a thermal energy storage mechanism.
    - Tested corrosion effects on Graphite, Silicon-Carbide (SiC) and Mullite 1350°C for 100 hours. Best performing to worst SiC, Graphite, Mullite
- Methane Pyrolysis
    - For cracking methane to carbon and hydrogen using liquid Tin. 800-1200°C
    - Reactor vessel exposed to Tin, uses Quartz glass lined vessel and pipework. Demonstrated at lab scale.
    - Borosilicate and Enamel lined pipes used industry for corrosive media.





The Conditions for Static vs Dynamic Systems

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Static Reservoir vs. Supply Loop

- Evaporation rate at surface Temperature 1200°C and 0Pa: 8.94E-4 kg/m^2s
  - Too high to allow a fixed reservoir within the target for 2 years.
  - Estimate would need to be refined with a more detailed operating life.
- Supply loop option allows for maintenance and re-supply of Tin.
- Supply loop investigates movement of Tin, and challenges this presents (impurities, corrosion, removal of H etc.)

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Potential for Impurities

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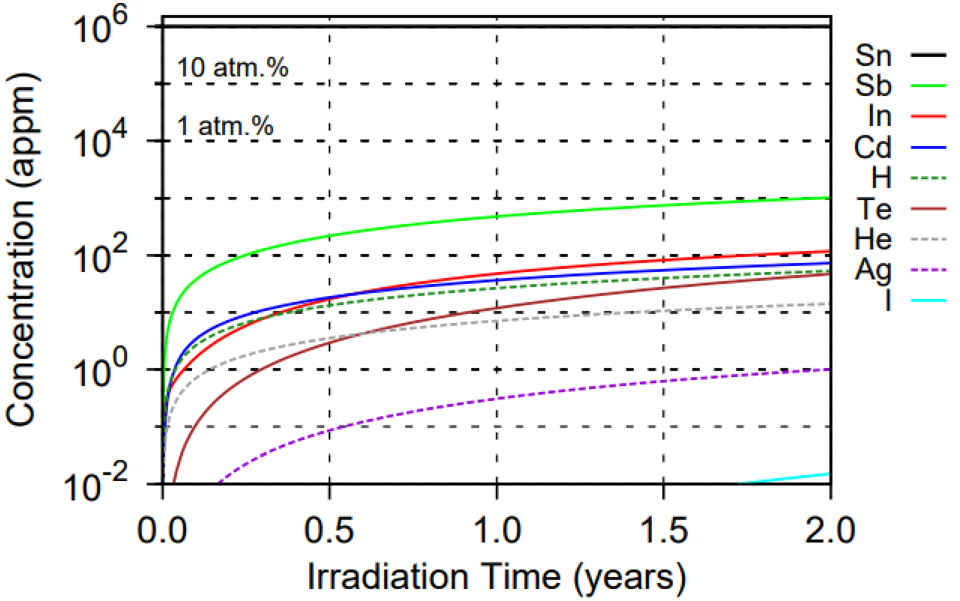
Impurity Control

- Ferritic impurities
  - Remove with magnetic filters
- Oxides
  - Reductive atmosphere in melt tank/glove box.(95%N_2, 5% H)
- Activation products:
  - Antimony, indium, tellurium, cadmium, hydrogen, helium, silver and iodine in order of concentration
  - Formation of Tellurium – Solid, could block CPS – Tin to be kept over 270°C.
  - Alternatively, cold traps could be used.



Tin first wall activation under DEMO like conditions, Gilbert, M. R, et al, (2015) Handbook of activation, transmutation, and radiation damage properties of the elements simulated using FISPACT-II & TENDL-2014; Magnetic Fusion Plants

Need to understand products with regards to solidification and consequential blocking of CPS

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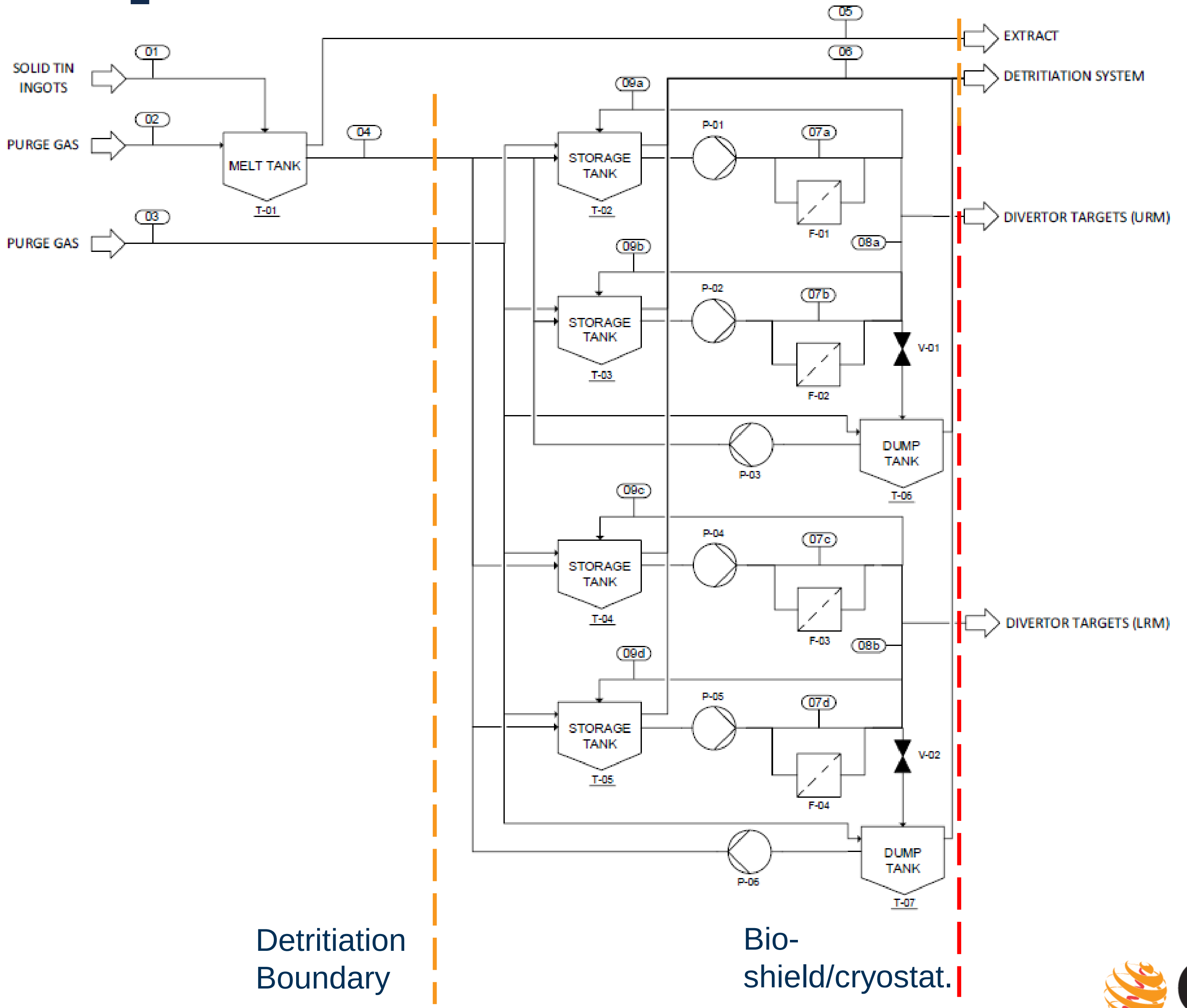
Distribution Concept - the LMDSS

Process Description

- Commercially pure Tin ingots into melt tank (T-01)
- Melt tank purged and re-filled to reductive atmosphere (95% Nitrogen, 5% Hydrogen)
- Tin Melted and fed to storage tanks via gravity.
- Pumped from storage tanks to ring mains in upper and or lower divertors. Parallel magnetic filters remove ferritic impurities
- Tin temperature maintained in range 280°C ≤ T ≤ 300°C. Trace heating only as back up for local freezing. Insulation and flow rates should be adequate to maintain liquid phase.

Component ID	Description
T-XX	Glass lined storage/melt tank
P-XX	Permanent Magnet Pump
F-XX	Magnetic Filter
V-XX	Valve (purge)



Readiness and Development Requirement

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Item Name	Description	Industry Technology Readiness Level (TRL)
Permanent Magnet Pump	Cylindrical Permanent Magnet Pump Maximum flow rate 10m³/hr, 7bar @ 600°C, static design pressure 10 bar. SAAS GmbH PMP300X250	TRL 7
Storage Tanks	Flat topped conical tank. Various sizes. Internal Borosilicate lining	Tank with borosilicate Lining: TRL 9 Quartz Coating: TRL 4
Piping	Stainless steel structural piping, Borosilicate wetted surface coating. trace heated, Insulation: Calcium Silicate	Piping: TRL 9 Quartz Coating: TRL 4
Valves	Control valve, Flow control through loop and ring main, Glass lined valve body, valve balls/plugs tungsten, tantalum or chromium plated.	Valve: TRL 5 Quartz Coating: TRL 4

Key components, description and indication of Technology Readiness Level (TRL), split where appropriate.

Technology Readiness Level (TRL)	Definition of technology maturity
TRL 9	Actual systems operating successfully in industry
TRL 8	Actual system completed and operating capability demonstrated through test and demonstration in working environment.
TRL 7	System prototype demonstration in working environment.
TRL 6	System/subsystem model or prototype demonstration in a relevant environment.
TRL 5	Component validation in relevant environment
TRL 4	Component validation in laboratory environment

Excerpt of relevant Technology Readiness Level (TRL) definitions applied

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Integration HAZOP

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Key Hazard (HAZID keyword reference)	Description	Mitigation
Loss of containment	Leak of Tin from the System or loss of containment from purge gas.	Additional tank volume has been added as a precaution. The main concern is loss of containment in the melt tank as this is outside of the detritiation boundary and where personnel may be working. To prevent back flow, the melt tank is the highest point in the LMASS, and tin is gravity fed into the rest of the LMASS. Ensure the ignition temperature of the surrounding materials is greater than the melting temperature/temperature of the tin in the system. Pressure monitoring in the melt tank, Flow monitoring of the purge feed, and Oxygen depletion monitoring (standard industrial practice).
External Dose	Radiation from storage tanks and associated pipe works due to activated tin returning through system. Shielding will be required on storage tank and associated pipe work.	Radiation monitoring in melt tank area where operators are situated. No back flow from divertor face. Elevation should account for in vessel pressurisation in Tokamak (fault case).
Corrosion/Erosion	Corrosion of LMASS piping or storage tank by liquid tin causing leaks (loss of containment) or blockages in the system	As for loss of containment
Ventilation	Exposure of gasses to operators. High ambient heat during transfer/ melting of liquid tin.	Evacuation alarms, Gas monitoring,
Conventional Safety - Heat	High temperature of tanks and pipes, heating elements and trace heating.	Temperature monitoring, Insulation on the supply lines.

Summary of key hazards and mitigation measures for LMASS loop concept

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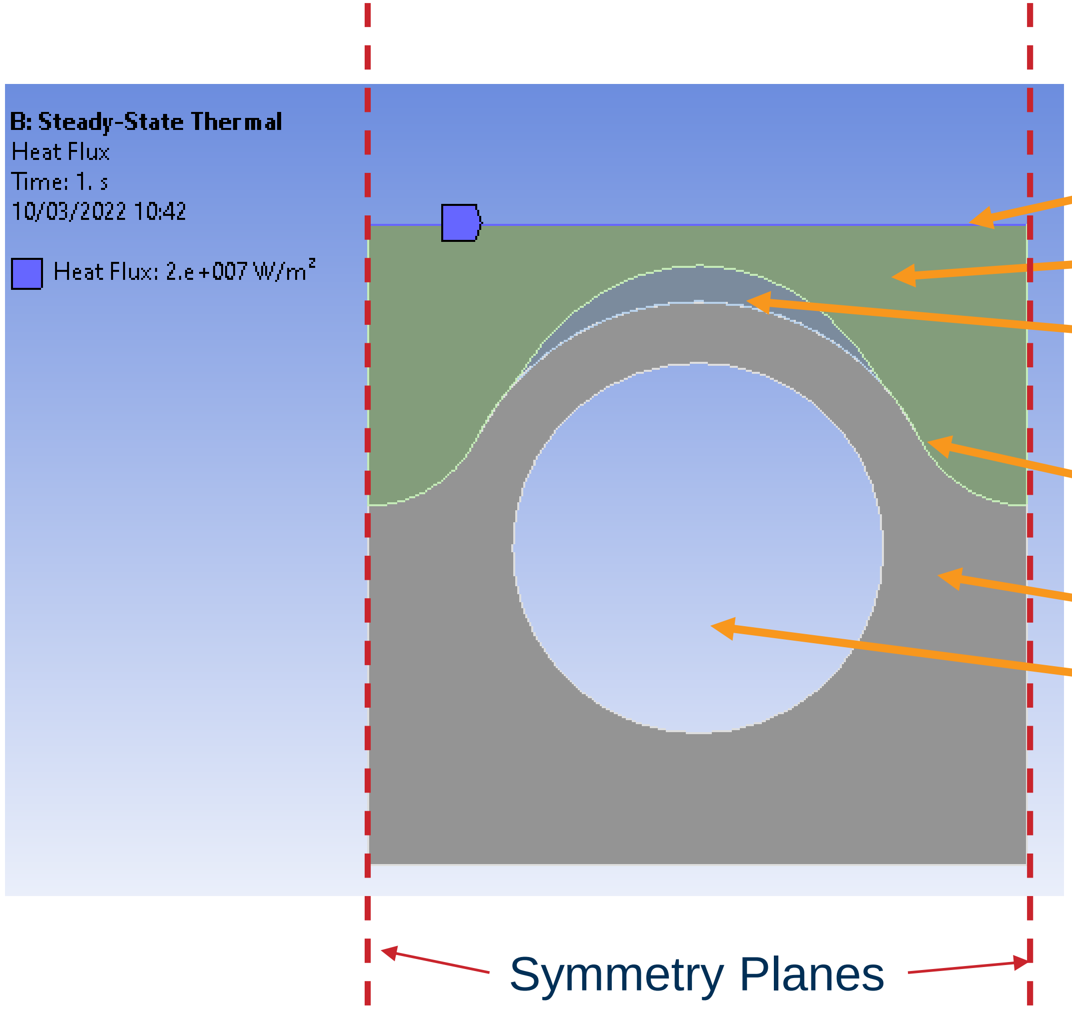
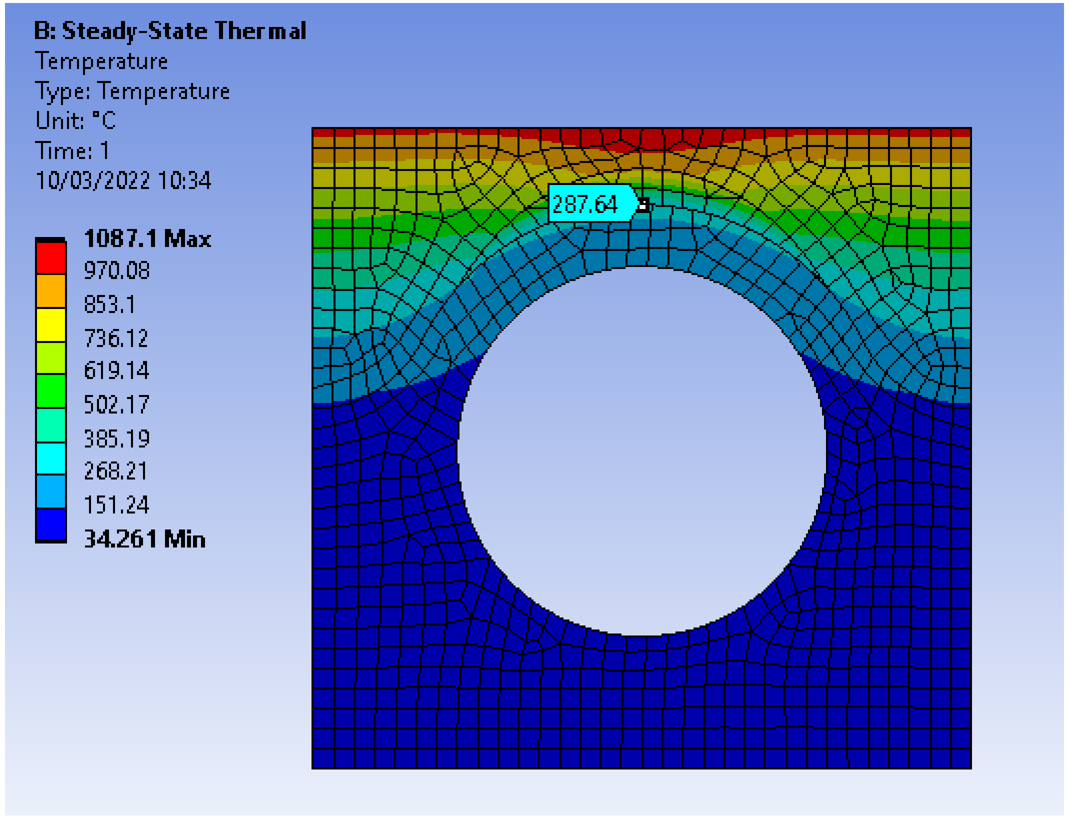
AWP2021 CCFE Target Design

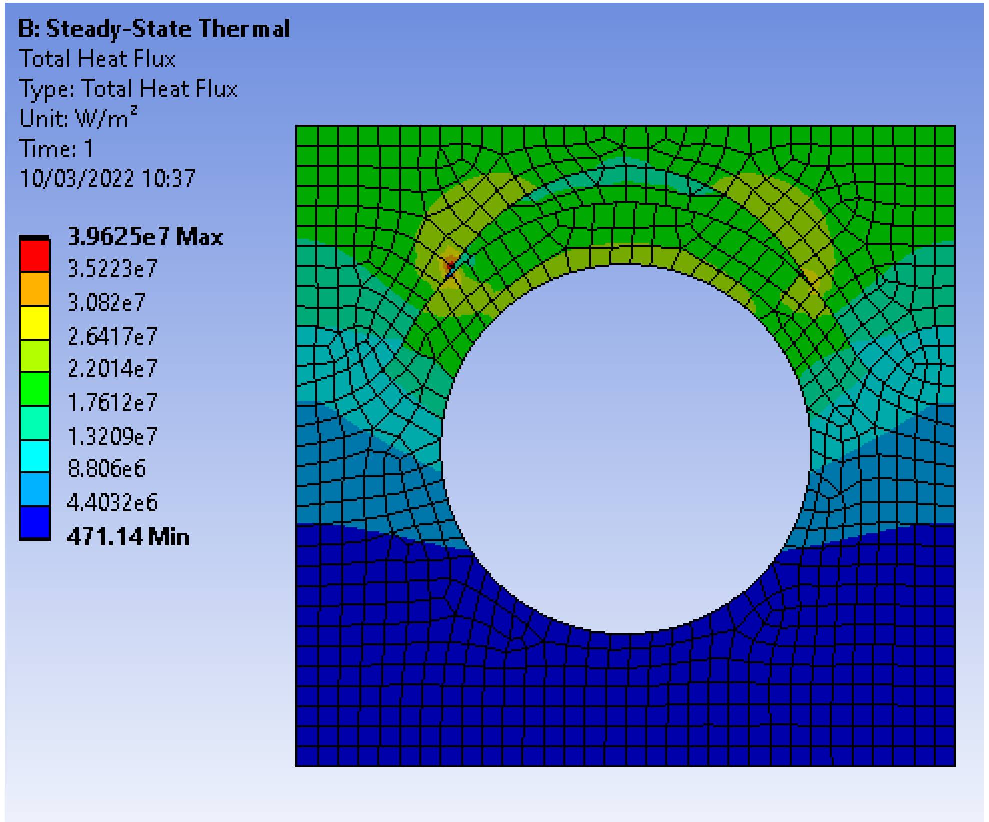


- 2 Component Design, bound together by wrapping braid.
- W CPS 3D Printed or Sintered (under compressive load)
- Crescent 'Thermal Break' provides more balance thermal resistance from surface to coolant
- Tapered sliding surfaces allow expansion
- CuCrZr Heat Sink (coated with W)
- Coolant: T=240°C, P=155 bar, V=14m/s

No need for mechanically bonded join as LM used for heat transfer between components

AWP2021 Target Performance





At incident heat flux of 20MW/m^2 results in a CHF margin of 1.44

Look at higher coolant temperatures as Sn may still be very viscous with localised volumes still undergoing phase changes at 240°C.

AWP2022 Proposed Work

- LMD Target Specific:
  - Supply of LM from ring main to targets (optimise to reduce MHD losses).
  - LM accountancy strategy – Open system (CPS) leak detection.
  - Manufacturing Routes for Realisation – joining techniques.
  - LMD Target Mock-Up
- LMD General Integration:
  - LMDSS integration with a de-tritiation/TFV system – challenges.
  - Penetrations of cryostat, Vacuum Vessel, Cassette and associated pipe analysis.
  - Handling of purge and protective atmosphere gases (start-up/shut down process).
    - Including purge methodology – i.e how to handle at CPS?
  - Process Flow Diagram, Process and Instrumentation Diagram and Process Calculations.

Questions?

Thanks for listening!