A Toroidal Confinement facility study and eventual experimental device to investigate a range of liquid metal divertor and first wall concepts *

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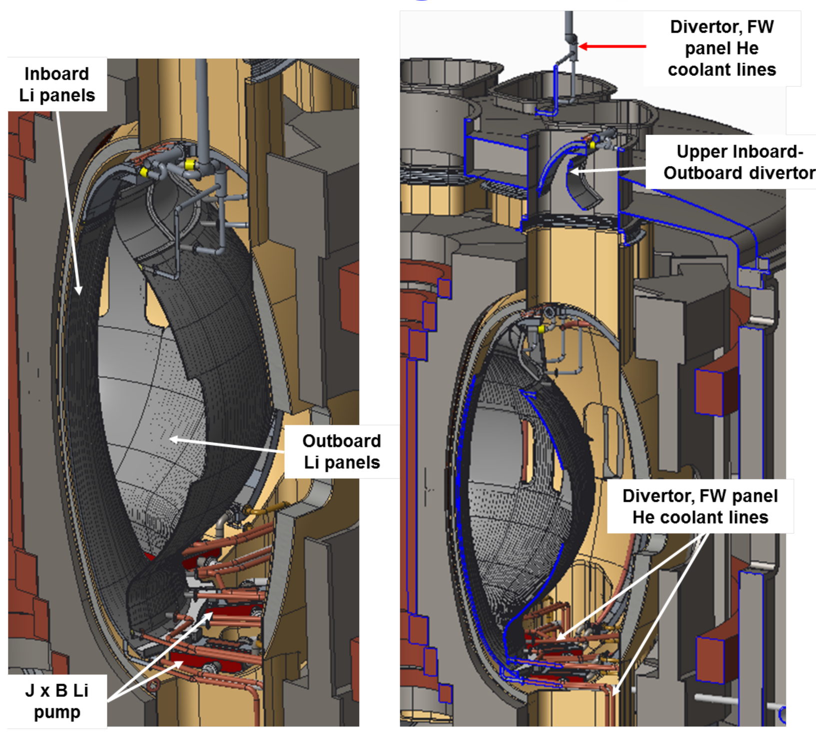
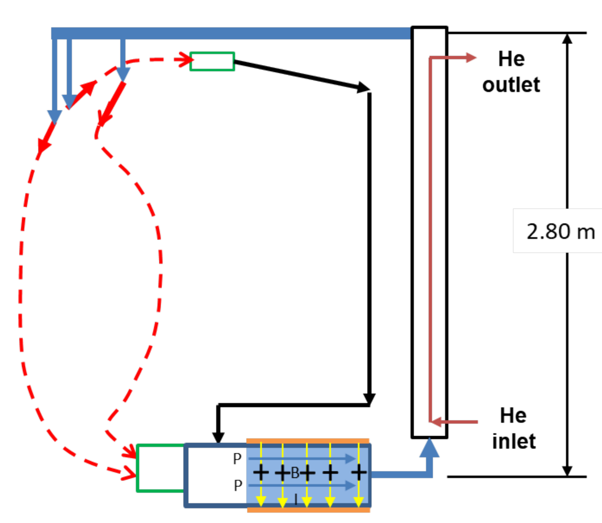
Abstract: A Toroidal Confinement facility study and development of a characteristic experimental device was undertaken to investigate a range of liquid metal divertor and first-wall concepts build on past and expected results from liquid metal experiments: the Lithium Tokamak Experiment (LTX), the National Spherical Torus Experiment Upgrade (NSTX-U), and the Experimental Advanced Superconducting Tokamak (EAST). The device configuration is driven by the need to adequately provide the concept details that depicts component features, space allocations, plumbing arrangements, thermal insulation, etc. of liquid metal (LM) systems. Of equal importance is to validate that the developed designs are upward compatible to exist within a blanket system of a DEMO or an eventual fusion power plant design. The proposed studies also builds upon recent low-A High Temperature Superconductor (HTS) tokamak pilot plant studies that incorporated a liquid metal divertor for high-heat-flux mitigation and as a means of reducing poloidal field coil current and simplifying the magnet layout and maintenance schemes. Tokamak aspect ratios in the range of A = 1.8 to 2.5 would be considered based upon recent pilot plant studies indicating this range would be optimal for fusion power production if high-current-density HTS magnets (or other high current density magnets) were utilized. This aspect ratio range is subject to change pending the results of the first 1 - 1.5 years of the study.

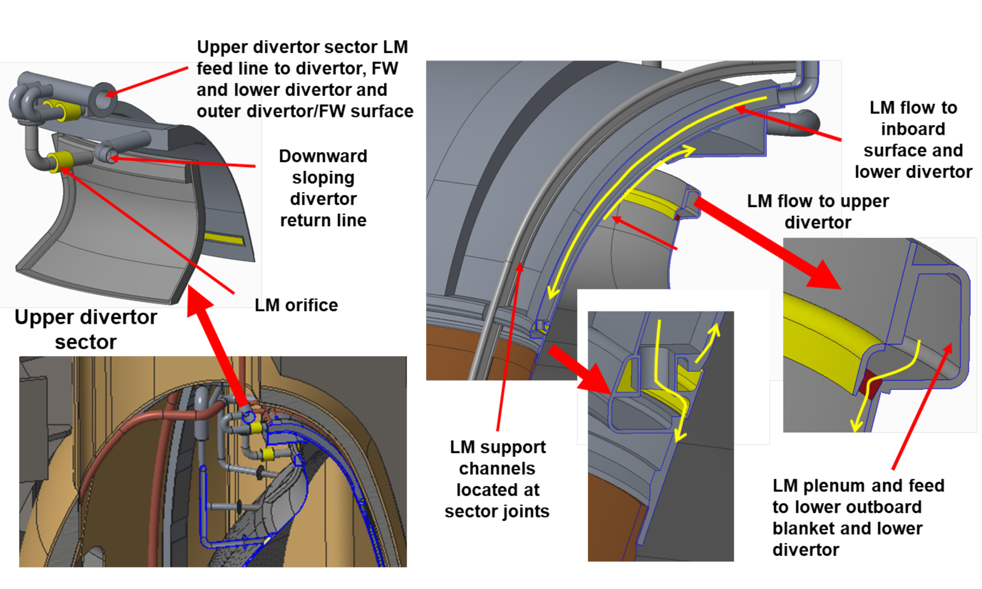
Fast flowing LM option



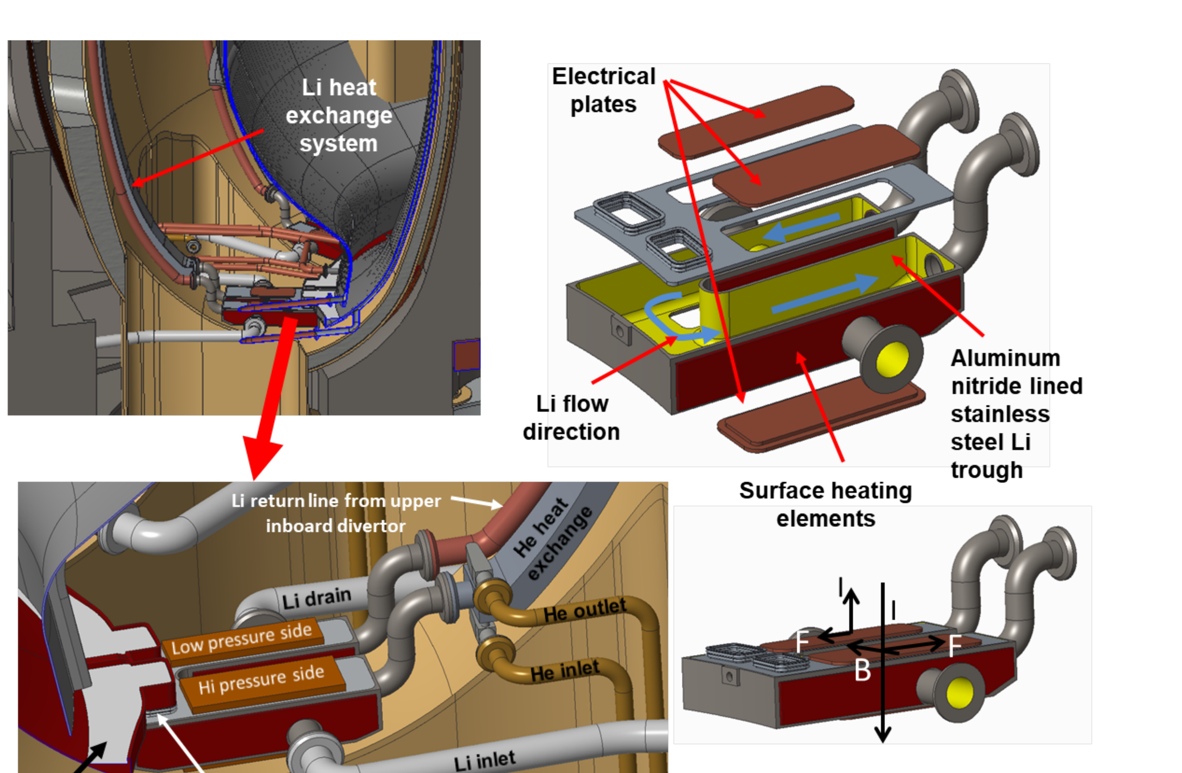
A structural shell comprising 20-18° outer panels and 10-36° inner panels includes the lower divertor surfaces. Electromagnetic EM Li pumping units are located at the bottom, in-line with each ten TF coils that supply Li to the 10 segmented inboard/outboard divertor/FW surfaces.



The line diagram depicts the flow system moving Li from the high side of the divertor to low filed side through the EM pump, with some Li passing through a He heat exchange system.



Upper divertor integrated inboard / outboard surface structure along with Li piping and flow details.



field, current and force vectors indicating the direction of flow

Local Li exchange / reservoir arrangement

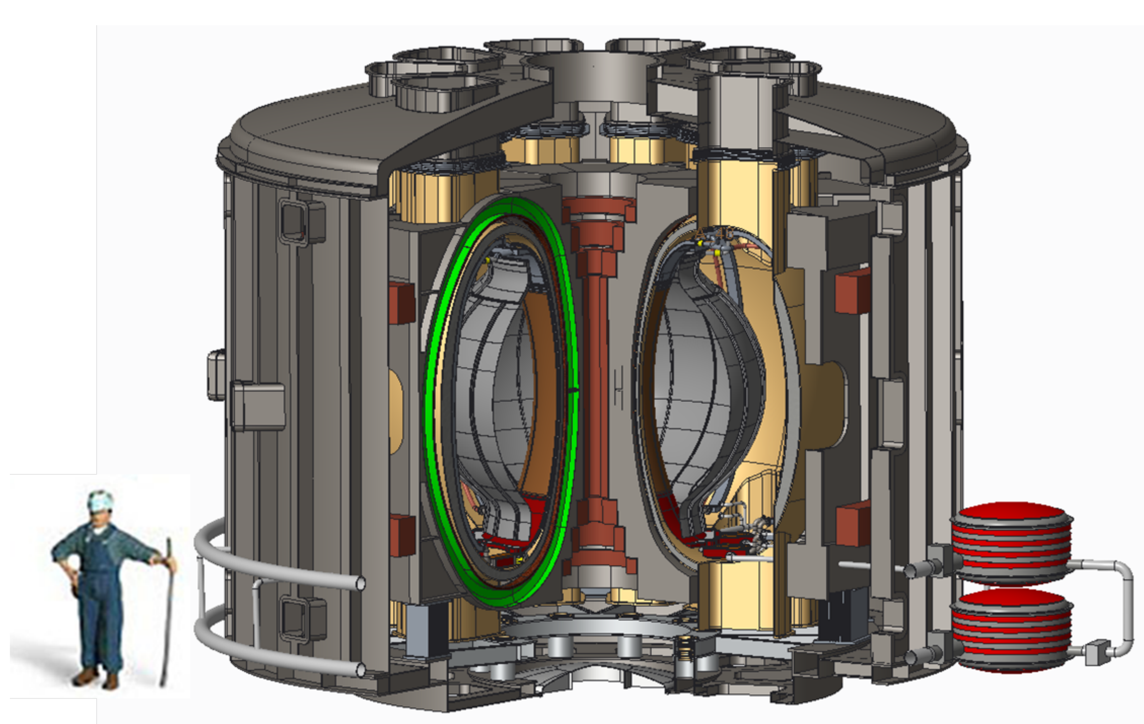
The EM pumping assembly has two chambers, a low pressure side (low applied current) where Li is returned from the upper inboard divertor, and a high pressure side (high applied current). Between the two chambers Li that accumulates in the base of the lower divertor drains into the EM chamber and moves to the high pressure side as part of the flow from the Li coming from the low pressure side. To maximize the flow pressure the EM unit is located as close as possible to the high field region given the limitations provided by the Li reservoir.

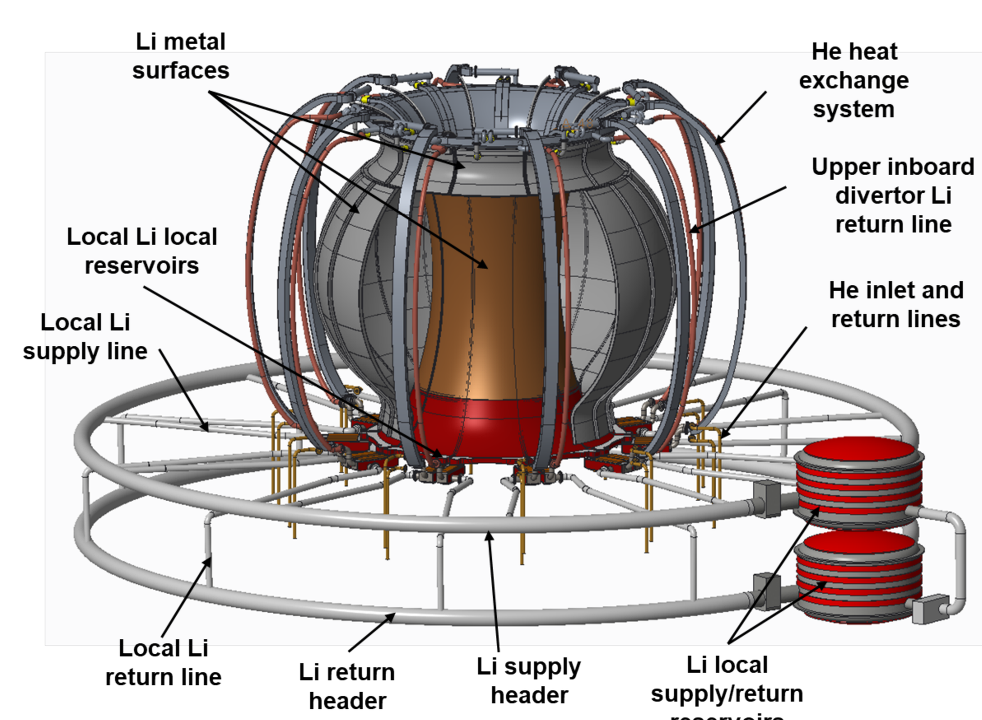
TC facility leading design goals

Leading goals which influenced the configuration development of the TC facility design include:

- Development of design features which allow the testing of key liquid-metal wall and divertor processes to help understand fuel & material retention in liquid metals,
- Investigation of different LM options - to include fast flowing liquid metal divertor/FW and a slow-flow, thin film divertor system and/or a possible combination of the two,
- Investigation of superconductor magnet designs to meet high field and high current density conditions,
- Set a device sized to supply sufficient solenoid space for an ohmic start-up, and
- limit the overall height of the device to allow it to be located within the existing test cell of the PPPL Tokamak Fusion Test Reactor (TFTR) building

TC facility general arrangement





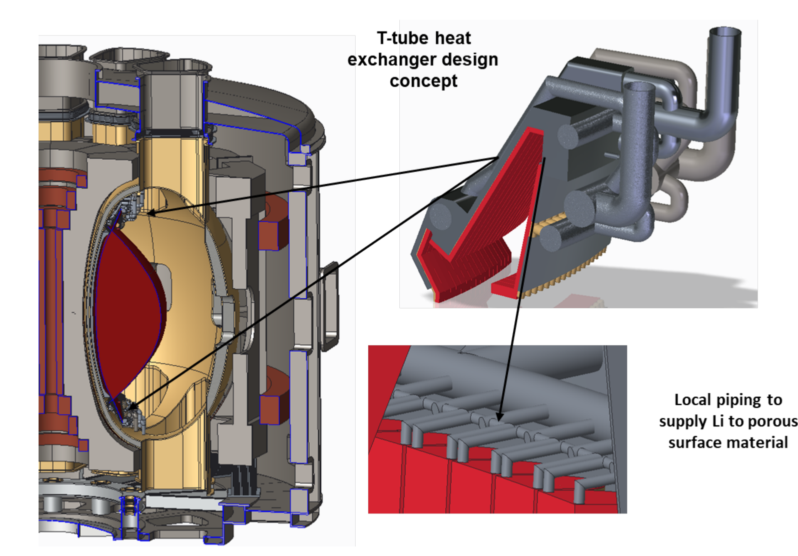
Machine parameters and inboard build details

Parameters	Values
Major radius (R)	1.0 m
Minor radius (a)	0.42 m
Divertor operation	Double-null
Aspect ratio	2.4
Elongation (k_x)	2.5
Triangularity (δx)	0.50
Magnetic field (B0)	4.75 T
Maximum TF field (Bmax)	12.2 T
Plasma current (Ip)	XXXX
Maximum burn time	

1.00 m R0 PPPL HTS ST radial build

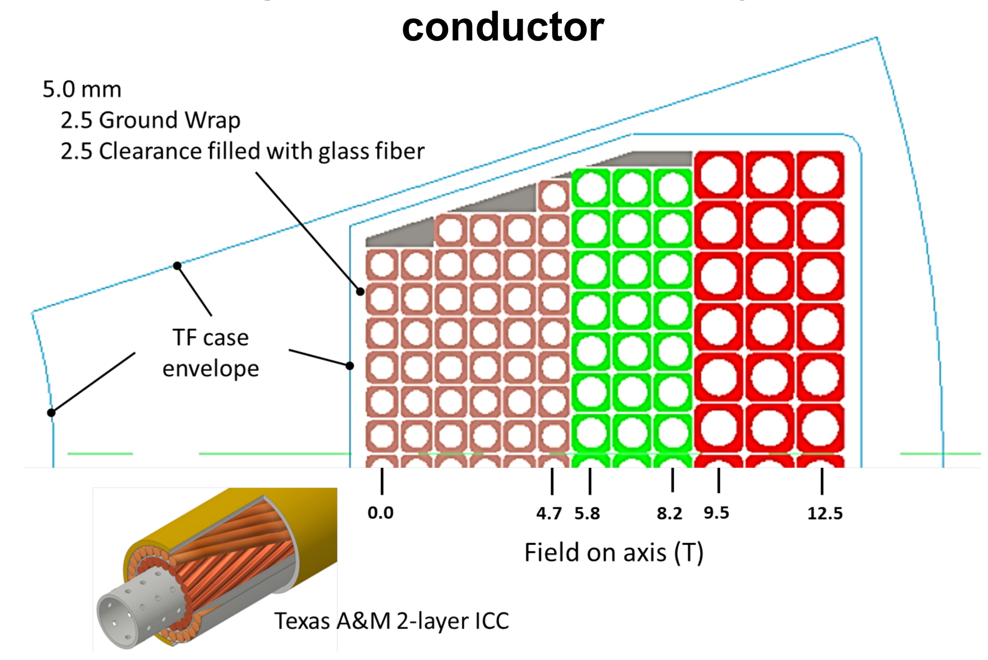
	10 TF coils	2.40	AR	
	COMP BUILD, Z=0			TOTAL
	(in)	(mm)	(mm)	(mm)
	Machine Center			0
	TF center bore	76		76.0
	OH coil	80.0	80	156.0
	OH - TF gap	12		168.0
TF inbd leg	Ext structure	70.5		238.5
	Clearance	2.50		
	ground wrap	2.50		243.5
	Winding pack thk	143.4		386.9
	ground wrap	2.50		389.4
	Clearance	2.50		391.9
	Ext structure	25.0	249	416.9
	TF-OH TPT / defl space	8.0		
	VV TPT	8.0		
	wedge coil asmbly fit up	0.0		
Thermal Insul	Thermal Shield	12.0		
	Min TF/VV Gap	5.0	33	450
inbd VV	VV shell thk	12		
	W shield / He cooled	30		
	VV shell thk	12	54	504
Shield	Piping/diagnostic/gags	31		535
Inbd Bkt	PbLi blanket	0		535
	Li metal surface girdle	3		538
FW	Li FW	5		543
	Bkt / Shield TPT	0.0		
	Plasma SO	40		583
	Plasma minor radii	416.7		
Plasma R0				1000

Slowflow, thin film divertor system



Capillary restrained forces provide a powerful means of stabilizing surfaces against various instabilities and could provide a general design strategy for slowflow, thin-film systems to avoid ejection into a confinement device. Shown is a concept definition of a divertor box arrangement based on an ARIES defined gas-cooled T-tube heat exchange design with a Li supply system feeding porous surface material.

TF winding pack based on TAM layer wound conductor



Texas A & M researchers are developing the CIC technology for a 40kA application:

- developing 2-layer CIC using Nb_3Sn and Bi-2212 strands
- capable of making U-bends on a 2 inch radius yet preserve I_c
- demountable spice joints for interconnects and leads

Overall winding pack current density (outside of the ground wrap) is 85 MA/ m^2

Summary comments

A Toroidal Confinement facility study was undertaken to investigate a range of liquid metal divertor and first-wall concepts and develop of a characteristic experimental device. This device can be used to address physics issues and assess the performance and operating characteristics of both the fast and slow flow LM divertor approaches. With the study centred on an ST, double null configuration a planned next phase is to develop a combined slow – fast flow LM system where a fast flow arrangement would be located at the bottom with a divertor pumping system included and a slow flow system located at the upper divertor position (with no pumping) and a slow flow LM design developed for the inboard and outboard surfaces. The final assessment will also include the upward ability to effectively integrate the TC facility design features within a DEMO fusion device and the definition of superconducting OH and TF coil systems that can meet planned performance and cost objectives.

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