Description of Thin Liquid Wall Protection w/Porous Walls

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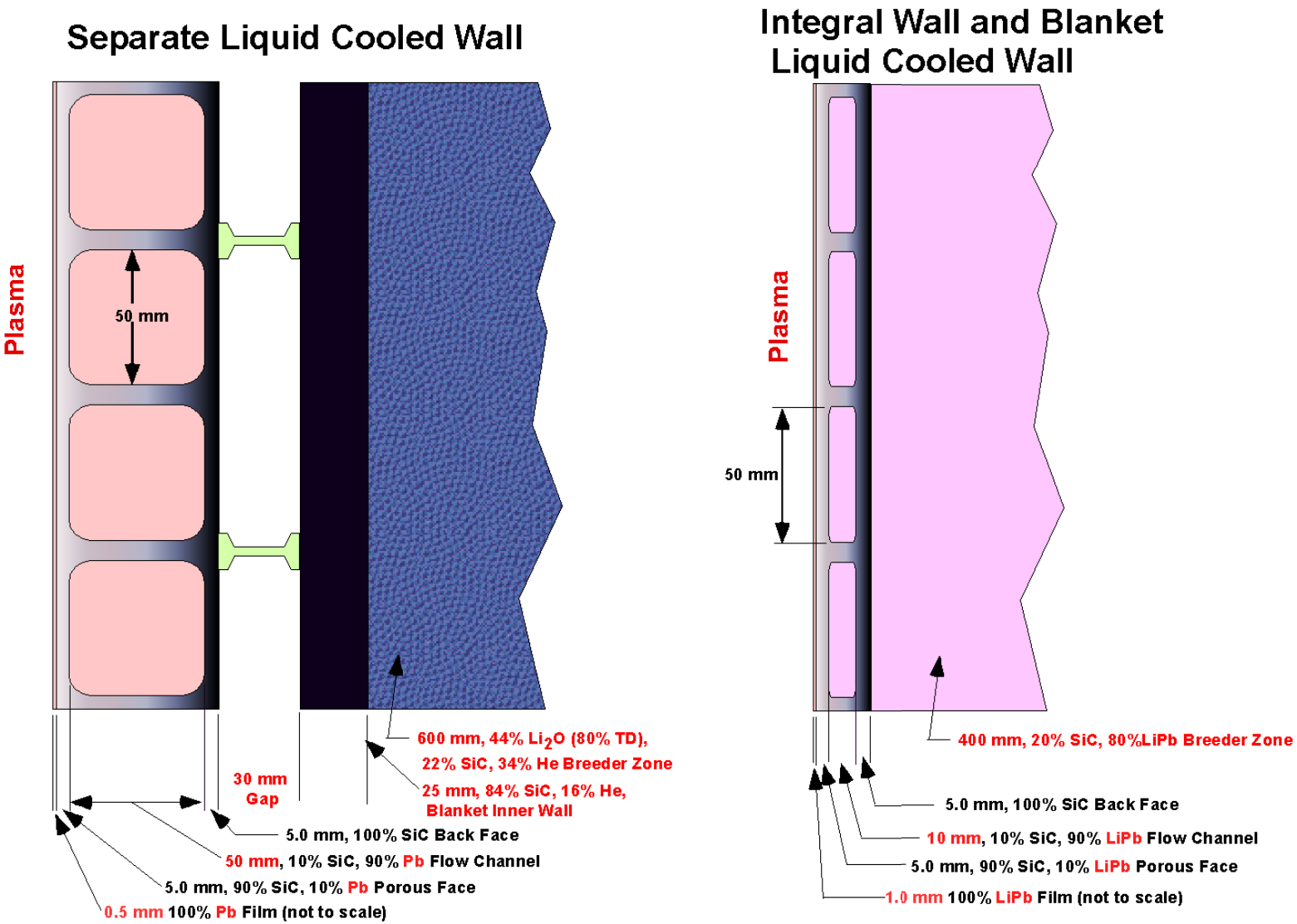
Description of the Thin,Wetted, Porous Wall Concepts

- A design basis for two blanket concepts is given to enable comparative analyses
- One is a stand-alone first wall and supply channel with a helium-cooled, solid breeding blanket
  - Lead is the coolant
- The other design is a liquid breeding blanket with a porous first wall and supply channel
  - Lithium-lead is the coolant

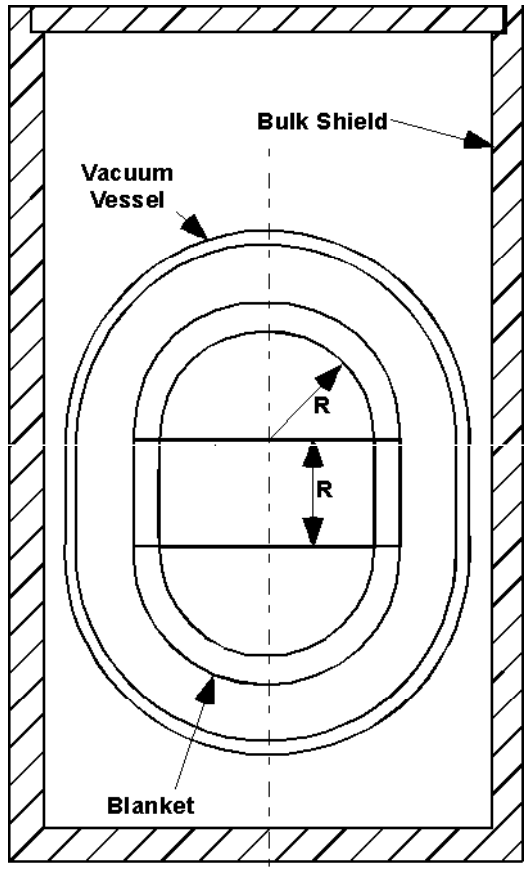
Thin Liquid Wall-Cooled Concepts



Cross-Section Through First Wall, Parallel with Flow Channel

Baseline Power Core Geometry

- First wall surface is a right circular cylinder of radius R_{fw} and height R_{fw} with hemispherical ends
- Wall surface area = $4\pi R_{fw}^2 + 2\pi R_{fw}^x H = 6\pi R_{fw}^2$



Definition of Heat Transport Systems

- Bulk shield closely fits around Vacuum Vessel (~2.25-2.4 x R_{fw} =11-12 m)
- Lead (or lithium-lead) intermediate heat exchangers are as close as possible outside shield
- Minimum piping run is ~30 m in and 30 m out including pumps
- IHX are roughly 1.4 m diameter and 14 m long for liquid metal section (1.0 m dia x 10 m for LiPb for reduced power level)

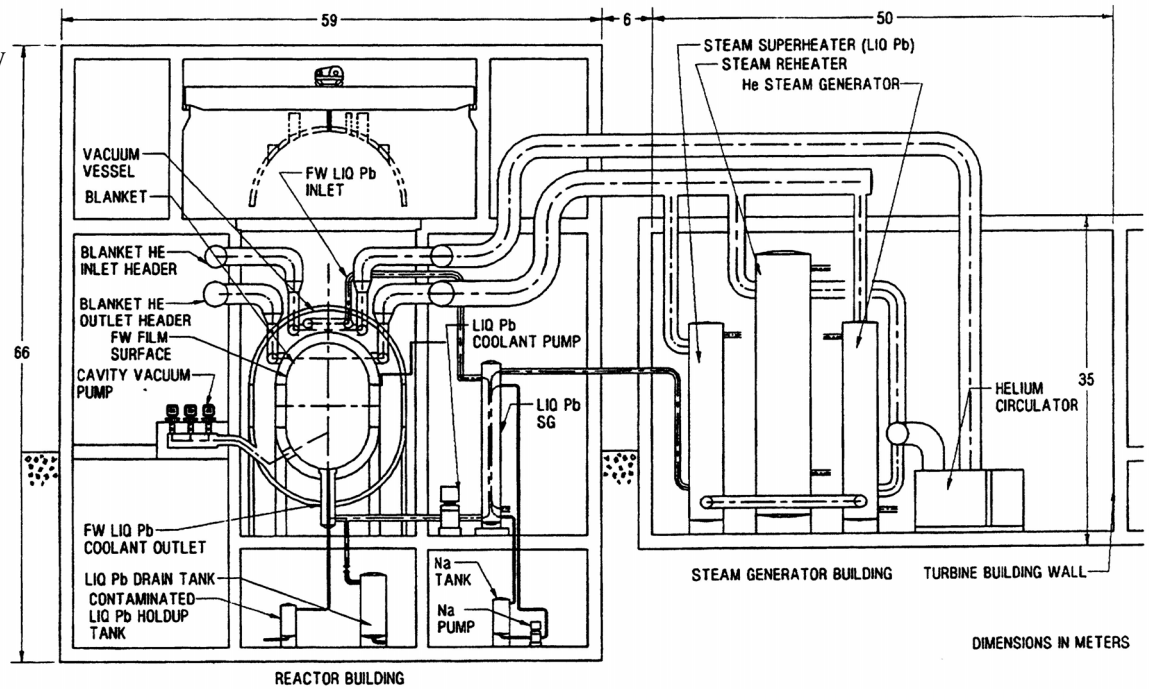


Figure 6.3.1-32. Elevation View – Reactor Systems/Heat Transport Interface

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Heating and Thermal Hydraulics

This data is based upon Prometheus Data for laser case
- **Promtheus wall geometry**
- **Lead coolant**
- **780 MW surface heat**
- **1267 MW total**

This is Prometheus Radial Build Up — **Laser Case**

Delta Temperature	150	Deg C		
Cp (Pb)	154	J/kg-K	Wall Rad	5 m
Lead Density	10400	kg/m3		
Coolant Velocity	**3.717**	m/s		

Zone		From: Tbl 6.8.1-2 Joule Heating,10^-13	Layer MW	Cumultv MW	Delta Area, m2	Cumulative Area, m2	Layer Thkns,mm	Cumulative Supply Layer Thickness,mm
Surface Heat			780	780	0.873488	0.873488	30.89330	30.8933
0.5mm Pb		0.05345	5.276449	785.2764	0.005909	0.879396	0.20898	31.1023
5 mm SiC90%,Pb10%		0.4084	40.31621	825.5927	0.045148	0.924545	1.59680	32.6991
5 mm SiC100%		0.2896	28.58858	854.1812	0.032015	0.95656	1.13230	33.8314
Add in Pb Flow Channel	Width,mm							
	26	2.17776	214.983	1069.164	0.24075		8.51479	42.3462
Adjusted joule heating	28	2.34528	231.5201	1085.701	0.259269		9.16977	43.0012
formula to balance	30	2.5128	248.0573	1102.238	0.277788		9.82475	43.6561
heat removal	32	2.68032	264.5944	1118.776	0.296308		10.47974	44.3111
	34	2.84784	281.1316	1135.313	0.314827		11.13472	44.9661
	36	3.01536	297.6687	1151.85	0.333346		11.78970	45.6211
	38	3.18288	314.2059	1168.387	0.351865		12.44469	46.2761
	40	3.3504	330.743	1184.924	0.370384		13.09967	46.9311
	42	3.51792	347.2802	1201.461	0.388904		13.75466	47.5860
	44	3.68544	363.8173	1217.999	0.407423		14.40964	48.2410
	46	3.85296	380.3545	1234.536	0.425942		15.06462	48.8960
	48	4.02048	396.8916	1251.073	0.444461		15.71961	49.5510
Balanced flow areas and	**50**	4.188	413.4288	**1267.61**	0.462981	1.41954	16.37459	**50.2060**
baseline thickness	52	4.35552	429.9659	1284.147	0.4815		17.02957	50.8610
	54	4.52304	446.5031	1300.684	0.500019		17.68456	51.5159
	56	4.69056	463.0402	1317.221	0.518538		18.33954	52.1709

Table 6.8.2-3

	From Calculation Above		Published	Corrected
Total FW Sys Heat Load	1267.61	MW	1268	1268
Mass Flow Rate	54875	kg/s	58770	54892
Volume Flow Rate	5.2764	m3/s	5.65	5.2781
Chnl Flow Area	1.4195405	m2	1.1775	1.422
Friction Factor	0.02		0.02	0.02
Coolant Path, L	12.85	m	12.85	12.85
Equiv Diameter, Dh	0.05	m	0.05	0.05
Pressure Drop	0.3693	Mpa	0.615	0.369
Pump Efficiency	0.85		0.85	0.85
Pump Power	2.292	MWe	4.1	2.29

Balanced flow rate is the same as Prometheus design

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Heating and Thermal Hydraulics

Consider this data as preliminary for rough sizing

- **Used ARIES wall configuration**
- **LiPb coolant**
- **570 MW surface heat, ref Perkins**
- **734 MW total (58% of Prometheus)**
- **350° delta T vs 150°**
- **Less pumping power**

This is Laila's Radial Build Up		Laser Case						
Delta Temperature	350	Deg C	Wall Rad	6	m			
Cp (LiPb)	188	J/kg-K						
LiPb Density	9400	kg/m3						
Coolant Velocity	5	m/s						
Zone		Joule Heating,10^-13	Layer MW	Cumultv MW	Delta Area, m2	Cumulative Area, m2	Layer Thkns,mm	Cumulative Supply Layer Thickness,mm
Surface Heat	From Perkins Data		570	570	0.184311	0.184311	5.43222	5.4322
1 mm LiPb		0.1069	10.5529	580.5529	0.003412	0.187723	0.10057	5.5328
5 mm SiC90%,Pb10%		0.5205	51.38244	631.9353	0.016615	0.204338	0.48969	6.0225
5 mm SiC100%		0.3945	38.94404	670.8794	0.012593	0.216931	0.37115	6.3936
Add in LiPb Flow Channel	Width,mm							
	5	0.4554	44.95594	715.8353	0.014537		0.42844	6.8221
Balanced flow areas	7	0.63756	62.93831	733.8177	0.020351	0.224689	0.59982	6.9934
	10	0.9108	89.91187	760.7913	0.029073		0.85688	7.2505
	28	2.55024	251.7532	922.6326	0.081405		2.39926	8.7929
Adjusted joule heating	30	2.7324	269.7356	940.615	0.08722		2.57064	8.9643
formula to balance	32	2.91456	287.718	958.5974	0.093034		2.74201	9.1356
heat removal	34	3.09672	305.7004	976.5797	0.098849		2.91339	9.3070
Note: joule heating may	36	3.27888	323.6827	994.5621	0.104664		3.08477	9.4784
be wrong for LiPb	38	3.46104	341.6651	1012.544	0.110478		3.25614	9.6498
	40	3.6432	359.6475	1030.527	0.116293		3.42752	9.8211
	42	3.82536	377.6299	1048.509	0.122108		3.59889	9.9925
	44	4.00752	395.6122	1066.492	0.127922		3.77027	10.1639
	46	4.18968	413.5946	1084.474	0.133737		3.94164	10.3353
	48	4.37184	431.577	1102.456	0.139552		4.11302	10.5066
	50	4.554	449.5594	1120.439	0.145366		4.28440	10.6780

	From Calculation Above	
Total FW Sys Heat Load	733.81769	MW
Mass Flow Rate	11152	kg/s
Volume Flow Rate	1.1864	m3/s
Chnl Flow Area	0.2247	m2
Friction Factor	0.020	
Coolant Path, L	13.85	m
Equiv Diameter, Dh	0.05	m
Pressure Drop	0.6510	Mpa
Pump Efficiency	0.85	
Pump Power	0.909	MWe

Balanced flow rate could be smaller than 10 mm (if nuclear heating is correct)

Calculations on Flow Rates and Volumes

Prometheus-L					Prometheus-H				ARIES Baseline			
Laser Radius	5 m				HI Radius	4.5 m			Radius	6 m		
Laser Surf Area	471.2 m2				HI Surf Area	381.7 m2			Surf Area	678.6 m2		
	Thkns, m	Vol %	Vol, m3	Mass, kg	Thkns, m	Vol %	Vol, m3	Mass, kg	Thkns, m	Vol %	Vol, m3	Mass, kg
Liquid Film	0.0005	1	0.236	2,450	0.0005	1	0.191	1,985	0.001	1	0.679	6,379
Porous wall	0.005	0.1	0.236	2,450	0.005	0.1	0.191	1,985	0.005	0.1	0.339	3,189
Channel	0.05	0.9	21.206	220,540	0.05	0.9	17.177	178,637	0.01	0.9	6.107	57,408
Total			21.677	225,441			17.558	182,607			7.125	66,976
			Fraction	0.09			Fraction	0.07			Fraction	0.09
Lead Piping												
	Diameter	T. Lngth	Vol, m3	Mass, kg	Diameter	T. Lngth	Vol, m3	Mass, kg	Diameter	T. Lngth	Vol, m3	Mass, kg
Supply (6)	0.61	29.5	51.728	537,967	0.61	30	52.604	547,085	0.3	31	13.148	123,587
Return (6)	0.61	29.5	51.728	537,967	0.61	30	52.604	547,085	0.3	31	13.148	123,587
Total			103.455	1,075,934			105.209	1,094,171			26.295	247,174
			Fraction	0.41			Fraction	0.42			Fraction	0.33
Intermediate Heat Exchangers, 6												
	Diameter	T. Lngth	Vol, m3	Mass, kg	Diameter	T. Lngth	Vol, m3	Mass, kg	Diameter	T. Lngth	Vol, m3	Mass, kg
	1.4	14	129.308	1,344,802	1.4	14	129.308	1,344,802	1	10	47.124	442,964
			Fraction	0.51			Fraction	0.51			Fraction	0.59
			Vol, m3	Mass, kg			Vol, m3	Mass, kg			Vol, m3	Mass, kg
Totals			254.440	2,646,177			252.075	2,621,579			80.544	757,114
			Laser				HI					
FW mass flow rate, kg/s			54,891		FW mass flow rate, kg/s		50,303		FW mass flow rate, kg/s		11,152	
Lead mass in main stream, kg			2,641,276		Lead mass in main stream, kg		2,617,609		LiPb mass in main stream, kg		747,546	
Time for complete fluid recycle, s			48		Time for complete fluid recycle, s		52		Time for complete fluid recycle, s		67	
Lead Coolant Velocity in FW, m/s			3.717		Lead Coolant Velocity in FW,m/s		3.77		Lead Coolant Velocity in FW,m/s		5.00	
Approximate Flow Length in FW, m			20.71		Approximate Flow Length in FW,m		18.64		Approximate Flow Length in FW,m		24.85	
Approximate Time in FW, s			5.57		Approximate Time in FW, s		4.94		Approximate Time in FW, s		4.97	
Fraction of Time in FW			0.116		Fraction of Time in FW		0.095		Fraction of Time in FW		0.074	

- **The mass and mass flow rate is much lower with ARIES LiPb coolant system**
  - **Less power transported at a higher delta T**
- **Residence time inside reactor is similar, but time outside is slightly longer**

Next Actions?

- **If these data are useful, I can update my analyses with the appropriate heat fluxes, configurations, and material parameters**