Spray Cooling of the First Wall

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Requirements for First Wall Cooling :

A) Surface heatflux > 1.5 MW/m^2

B) Extraction of high grade heat

- First wall heat is > 20% of total heat
- Required thermal efficiency >40%

C) Minimum impact on breeding ratio

- Neutron moderation
- Neutron absorbtion

D) Low coolant pressure desireable :

- Primary stresses in wall
- Impact on reliability

E) Coolant compatible with breeder material

Candidate Coolants for First Wall :

A) Helium

- **High coolant pressure and velocity required for sufficient heat transfer**
- **Large ΔT between FW and coolant limits efficiency,**
- **Large manifolds required.**

B) Water

- **Not compatible with liquid metal breeder,**
- **Extremely high pressure required for high efficiency,**
- **Neutron moderation reduces tritium breeding.**

C) Single phase liquid metal

- **Electrically insulating coatings required,**
- **Heat transfer in magnetic field rather poor (large difference T_{wall}-T_{bulk} requires high velocity and limits exit temperature)**

D) Two phase liquid metal

- **High heat of evaporation reduces required flow rate decisively,**
- **Low density of liquid metal vapor results in high velocity and requires large fraction of flow cross section,**
- **Large vapor volume fraction leads to burn-out at the FW**

Spray Cooling of the First Wall :

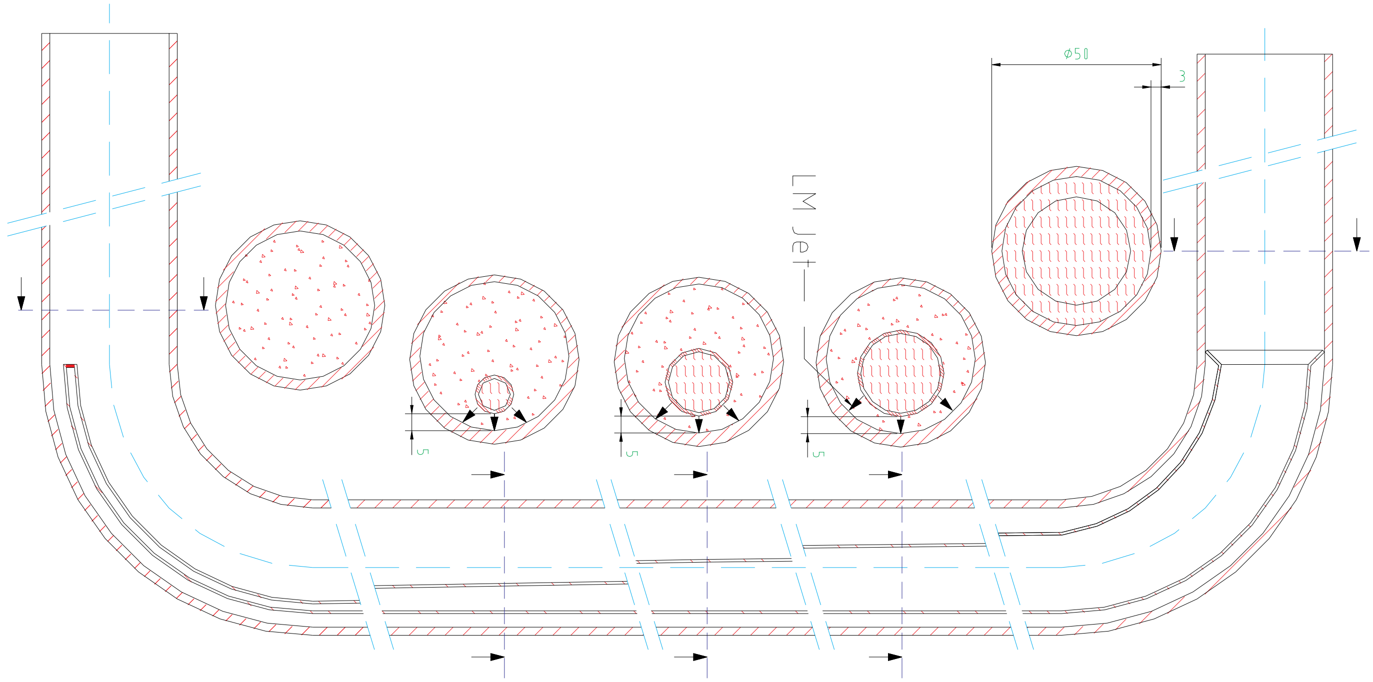
- **Array of liquid metal jets hit the backside of the first wall, assuring that the first wall remains wetted,**

- **Entire FW heat is removed by evaporation,**

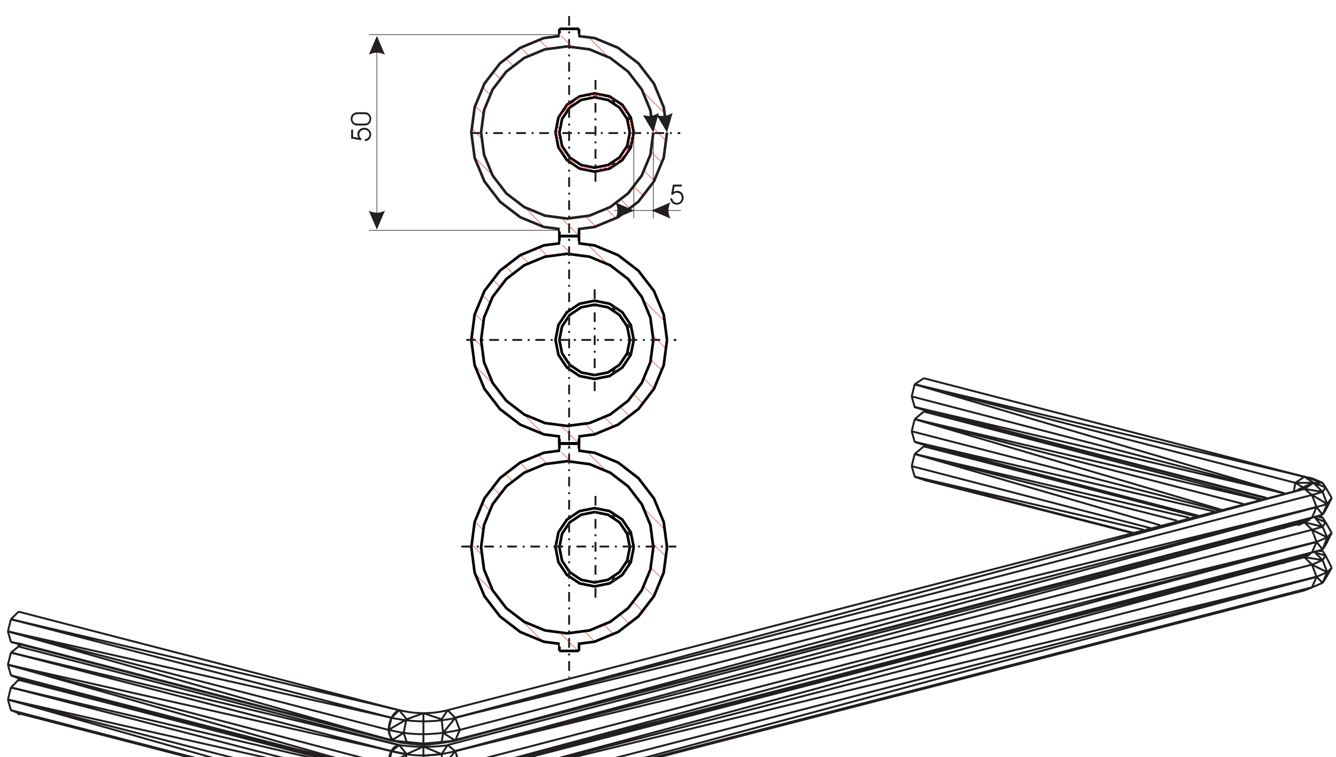
- **Required liquid metal velocity so low that probably no insulating coatings required,**

- **Heat transfer by evaporation at the FW and condensation in the HX requires very low ΔT and leads therefore to high efficiency,**

- **Low vapor pressure of candidate liquid metals (K,Na,Li) reduces primary stresses in FW decisively.**



PLASMA



For Comparison : Potassium topping cycle

W.R.Cambers, A.P. Fraas, M.N.Ozisik :
A Potassium-Steam Binary Vapor Cycle for Nuclear Power Plants , ORNL-3584, May 1964

A.P. Fraas:
A Potassium-Steam Binary Vapor Cycle for Better Fuel Economy and Reduced Thermal Pollution,
Transaction of the ASME,
Journal of engineering for power , Jan.1973 , p. 53-63

R.S. Holcomb :
Alkali Metal Rankine Topping Cycle; System design and Development. 17. IECEL, August 1982, Los Angeles

Potassium topping cycle:

Pressure/temperature at turbine inlet
0.224 MPa/ 850°C
Pressure/temperature at condenser exit
0.006 MPa/ 520°C

Proposed structural material in potassium loop : Incoloy 800

Estimated overall thermal efficiency 54 %

Example of a FW Tube with Spray Cooling

toroidal length of tube	**3 m**
tube inner diameter	**50 mm**
wall thickness front/back	**3 mm/ 2 mm**
pitch of tubes	**60 mm**

tube material : **refractory metal**

coolant : sodium at **1200K/ 0.15 MPa**

heat of evaporation	**3849 kJ/kg**
vapor density	**0.391 kg/m^3**
LM density	**731 kg/m^3**
velocity of sound	**724 m/s**

For one Tube :

heat input by surface heatflux
$Q' = 2\ MW/m^2 * 3\ m * 0.06\ m = 0.36\ MW$

vapor generation
$M' = 360\ kW : 3849\ kWs/kg = 0.0935\ kg/s$

LM volume flow rate
$V'_{lm} = 0.0935\ kg/s : 731\ kg/m^3 = 0.128\ E\text{-}3\ m^3/s$

vapor flow rate
$V'_{vap} = 0.0935\ kg/s : 0.391\ kg/m^3 = 0.239\ m^3/s$

flow cross section
$A = \pi/4 * (0.05\ m)^2 = 19.4\ E\text{-}4\ m^2$

LM velocity $v_{lm} = 0.066\ m/s$

vapor velocity $v_{vap} = 123\ m/s$

vapor pressure drop in 10 m long tube
$\Delta P = 10\ m : 0.05m * 0.03 * 0.391\ kg/m^3 : 2 * (123\ m/s)^2$
$= 17740\ Pa = 0.01774\ MPa$ = 12% of vapor pressure

Velocity of Liquid Metal Jets :

Assumptions : **Jet diameter 0.5 mm**
Cooling surface for one jet 1 cm^2

Volume flow rate of one jet

$$V'_{Jet} = 200 W/cm^2 * 1.\ cm^2 : (3849\ E3\ Ws/kg * 731\ kg/m^3)$$
$$= 7.11\ E\text{-}8\ m^3/s$$

Velocity of jet (diameter 0.5 mm)

$$v_{Jet} = 0.362\ m/s$$

Conclusions :

- **Spray cooling with an evaporating alkali metal can remove heat fluxes much higher than 2 MW/m^2.**

- **Heat from the FW can be extracted with alkali metal vapor and transfered to helium of a closed cycle gas turbine power conversion system at a maximum helium temperature up to 900°C.**

- **Temperature difference between the FW and the helium in the power conversion system is minimized by the excellent heat transfer by evaporation(FW) and condensation(HX).**

- **Low coolant pressure (0.15 Mpa in the example) minimizes primary stresses in FW, increasing FW lifetime and decreasing failure rate.**

- **Suitable fluids are K, Na, Li (in the order of increasing operating temperature).**

- **Experience with heat pipes shows that for example Na works with Stainless steel, Incoloy 800, Hastelloy X and Molybdenum.
  Li works with Tungsten, Molybdenum, Tantalum, Niobium**