The desire to achieve both high power density and high power conversion efficiency leads to several required features of a first wall and blanket concept. Achieving high power density means that the coolant heat removal capability must be high and the first wall material should have attractive thermophysical properties (high thermal conductivity, low thermal expansion, etc.). Achieving high power conversion efficiency means that the first wall and blanket should operate at very high temperatures. Materials operating at very high temperatures generally have limited strength, and therefore, such a concept should operate at low primary stresses. This means that the coolant pressure should be as low as possible, and the temperatures throughout the blanket should be as uniform as possible to reduce thermal stresses.

One system that has this potential is the EVOLVE (Evaporation of Lithium and Vapor Extraction) concept. The key feature of the EVOLVE concept is the use of the heat of vaporization of lithium (about 10 times higher than water) as the primary means for capturing and removing the fusion power. A reasonable range of boiling temperatures of this alkali metal is 1200 to 1400 C, corresponding with a saturation pressure of 0.035 to 0.2 MPa. Calculations indicate that a evaporative system with Li at ~1200 C can remove a first wall surface heat flux of >2 MW/m2 with an accompanying neutron wall load of > 10 MW/m2. The system has the following characteristics.

1. The high operating temperature translates naturally to a high power conversion efficiency.
2. The choices for structural materials are limited to high temperature refractory alloys. A tungsten alloy, e.g. W-5%Re, is the primary candidate as a structural material, with tantalum alloys as the back-up.
3. The vapor operating pressure is very low (sub-atmospheric), resulting in a very low primary stress in the structure.
4. The temperature variation throughout the first wall and blanket is low, resulting in low structural distortion and thermal stresses.
5. The lithium flow rate is approximately a factor of ten slower than that required for self-cooled first wall and blanket. The low velocity means that an insulator coating is not required to avoid an excessive MHD pressure drop.

The areas addressed are first wall and blanket design, tritium breeding, activation and waste, power conversion, first wall thermo-mechanical behavior, tritium extraction, and critical issues. The key features of the design are summarized in Table 1.

Table 1. Key Features of the EVOLVE Concept

Feature	**Value**
Heat capture and removal	Li vapor
Li vapor pressure	0.035 MPa
Li vapor velocity	~500 m/s
Structural material	Tungsten
Operating temperature	~1200 C
First wall heat flux	2 MW/m^2
Neutron wall load	10 MW/m^2
Tritium Breeding Ratio (local 2D)	1.37
Power Conversion Efficiency	~57%

The cross-section design of the EVOVE concept is illustrated in Fig.1. In the EVOLVE concept, first wall and primary breeding zone are combined into one unit. Behind this unit, there is as a separate component a high temperature shield at the inboard region and a secondary breeding blanket at the outboard region. Behind the secondary breeding zone there is , as a separate component, an additional high temperature shield, required in order to meet the shielding requirements of vacuum vessel and magnets.

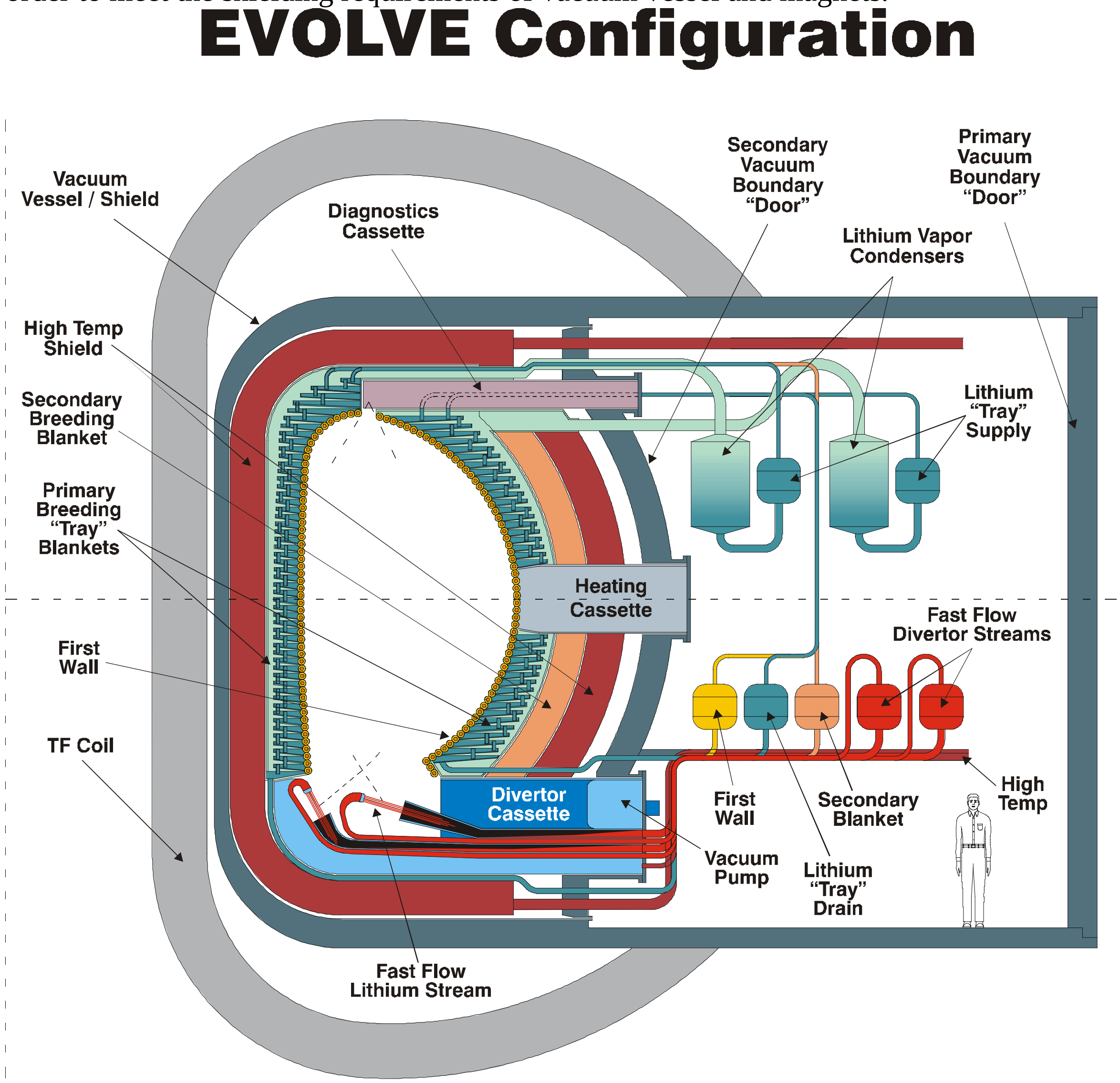

Figure 1. Cross-sectional view of the EVOLVE first wall/blanket concept

The first wall consists of a tube bank arranged in the toriodal direction as shown in Fig.2. Within each tube is another tube which caries liquid lithium. Slits in the inner tube provide the means for the liquid lithium to spray into the annulus of the outer tube and vaporize. For a surface heat flux of 2 MW/m2, a toroidal segment width of 3 m, and the tube dimensions given above, a boiling temperature of 1200 C (saturation pressure 0.035 MPa) results in a liquid metal velocity in the feed tube of about I m/s and a vapor velocity of about 500 m/s. This is about 1/3 of the sonic velocity and results in a tolerable pressure drop.

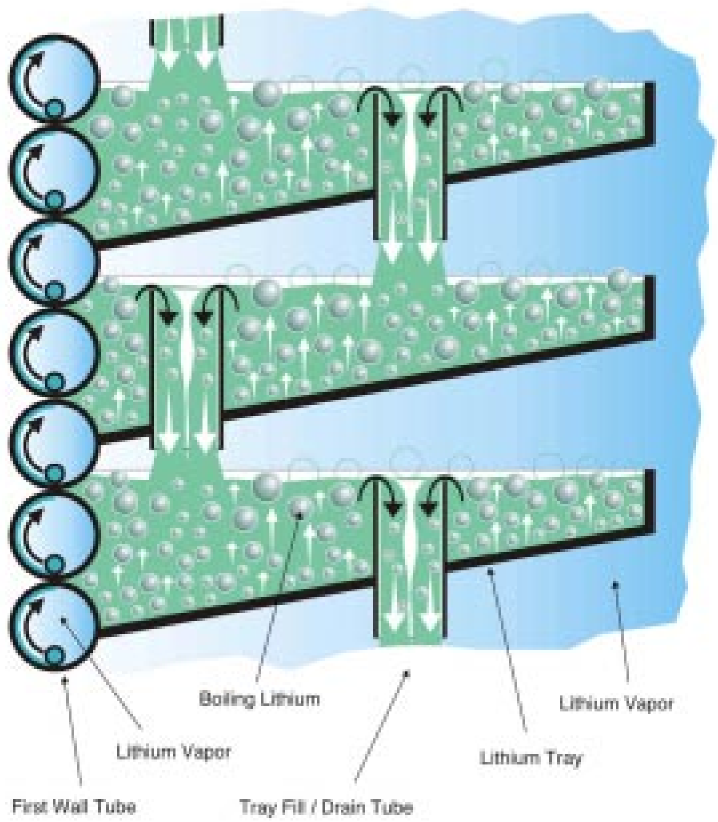

Figure 2. Schematic of EVLOVE first wall tubes and blanket trays containing Li

The blanket consists of a number of trays, stacked poloidally, containing liquid lithium. A space is left between trays to allow the Li vapor to be removed from the blanket. Each tray contains a lithium pool with a height of 10 to 20 cm, which is maintained constant by a system of overflow tubes. The large volume heating of the lithium leads to boiling. The vapor bubbles have to rise in the pool and separate from the liquid metal at the surface. From here the vapor flows a short distance in parallel to the surface before it enters the vertical vapor manifold. Entrained liquid metal will be separated there. Behind the trays is a manifold, approximately 20 cm thick, for collecting the Li vapor. The total radial thickness of the first wall and blanket is approximately 70 cm.

Two-dimensional (2-D) neutronics modeling of the front evaporation cooled blanket of EVOLVE is needed to properly account for the poloidal heterogeniety and gaps between trays. The R-Z geometrical 2-D model used in the calculation includes the FW, trays with Li vapor manifold, secondary breeding blanket, shield, VV, and magnet in both the IB and OB regions. Both the IB and OB regions are modeled simultaneously to account for the toroidal effects. The TWODANT module of the DANTSYS 3.0 discrete ordinates particle transport code system was utilized.The overall TBR calculated for the reference design using the 2-D model is 1.37. It is based on the conservative assumption of no breeding in the divertor region. 69.8% of tritium breeding occurs in the trays (57.3% OB and 12.5% IB). The OB secondary blanket contributes 27.7% of the total overall TBR (20.2% behind trays and 7.5% between trays). The contribution of the shield is only 2.5% (1% OB and 1.5% IB). Tritium breeding has a comfortable margin that allows for design flexibility.

There are two coolant streams exiting from the blanket. The front part of the blanket, including the first wall, is cooled by boiling lithium, which carries ~2/3 of the total thermal power. The back part of the blanket is cooled by a conventional self-cooled liquid lithium blanket with an exit temperature of also 1200C, which carries the other 1/3 of the thermal power. The two blanket coolant streams will be fed to two heat exchangers to transfer the thermal energy to a helium loop. The reason that He is used for the secondary coolant is that a closed cycle gas turbine can be used for very efficient power conversion. The two lithium streams exit from the blanket operates in series, with the liquid lithium stream to heat up the secondary He from 700 to 800C, while the high temperature lithium vapor super heat the same He stream from 800 to 1000C. The He at 1000C will enter a He turbine for power conversion. With a very high He temperature, and very high recuperator, compressor and turbine efficiencies, a very high cycle efficiency of 57.7% is calculated. This thermal efficiency includes the pumping power of the secondary He stream, but does not include the pumping power of either of the lithium streams.

Finite element thermal and stress analyses have been performed for the first wall subjected to surface heat fluxes of 1.5 and 2 MW/m^2, a coolant temperature of 1200°C, and a coolant pressure of 0.05 MPa. A single tungsten tube of radius 2 cm and wall thickness of 3 mm deforming under generalized plane strain condition is considered. The primary membrane stress in the EVOLVE first wall is so low that neither low-temperature nor high-temperature ratcheting should be a limiting criterion for the surface heat flux. The peak surface heat flux will be controlled either by creep-fatigue (which is not considered here) or possibly by brittle fracture (due to helium-embrittlement). The temperature distribution for a peak surface heat flux of 2 MW/m^2 and a heat transfer coefficient of 40,000 W/m^2/°C shows a peak temperature of 1317°C. The peak stress intensity is 158 MPa, which easily satisfies the ratcheting limits. Very little ductility is needed maintain the allowable stress limit at a high value. For example, if the uniform elongation remains higher than 2% or the reduction in area at failure is >1%, then the allowable stress is > 300 MPa.

The EVOLVE concept is at an early stage of evaluation. At this stage, it is important to assess the potential of the concept, identify crucial issues, and to define needed R&D work to remove resolve those issues. The critical issues to be addressed in the near future are:

1. *Will the backside of the first wall remain wetted under all conditions?*
2. Will the vapor generated in the stagnant boiling pools of the primary breeding region separate fast enough from the liquid metal?
3. Will the liquid metal overflow system work and lead to equal liquid metal pressure in each tray?.

4. Is it possible to fabricate entire blanket segments of tungsten or tungsten- alloys in spite of their low ductility and their limited weldability?
5. How will the structural material behave under intense neutron irradiation?
6. Will the high after heat in tungsten cause a safety problem in case of a LOCA ?