EVALUATION OF THE TUNGSTEN ALLOY VAPORIZING LITHIUM FIRST WALL AND BLANKET CONCEPT

An Overview of the Phase–II Evaluation

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APEX-TASK IV-Phase-I (FY1999)

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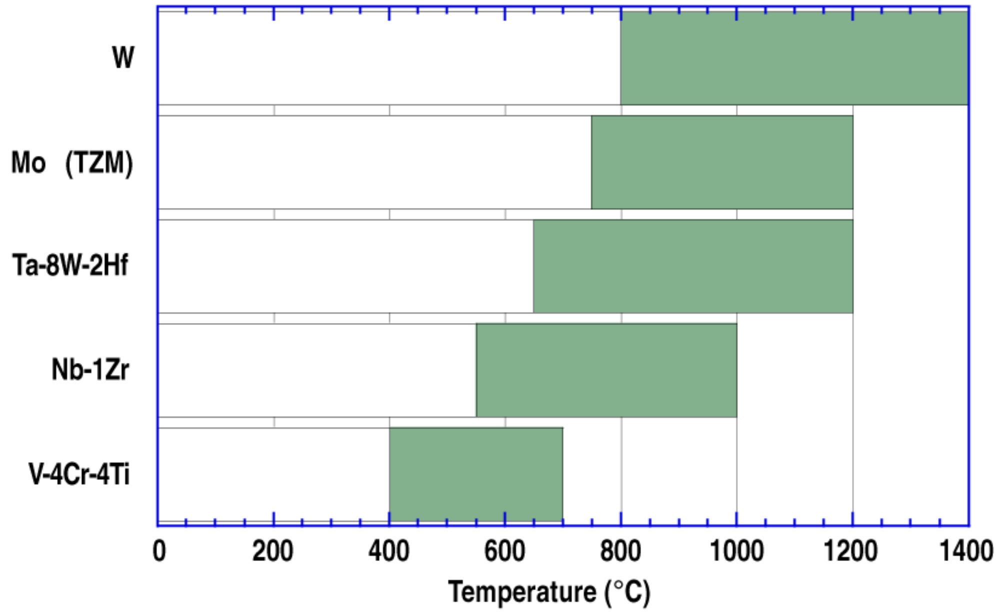
(Evaporation of Lithium and Vapor Extraction)

- W-5%Re is the candidate structural material
- High strength and high K_{th} W-alloy is a very attractive high performance structural material
- Due to projected embrittlement properties, we design to $T_{min} > 1000°C$ and $T_{max} < 1400°C$
- High operating temperature implies high CCGT power conversion efficiency (~57%) is possible
- For heat removal, vaporizing lithium allows very low operating pressure ~0.04 MPa
- With T_{in} = 900°C and T_{out} = 1200°C the temperature variation throughout the first wall and blanket is minimized
- Slow liquid lithium flow rate implies MHD insulator coating is not required at the first wall and blanket

Estimated Operating Temperature Limits for Refractory Alloys in Fusion Reactors



- Lower temperature limit based on radiation hardening/ fracture toughness embrittlement (K_{1C} <30 MPa-$m^{1/2}$) — large uncertainty for W due to lack of data

- Upper temperature limit based on 100 MPa creep strength (2% in 1000 h); chemical compatibility considerations may cause further decreases in the max operating temp

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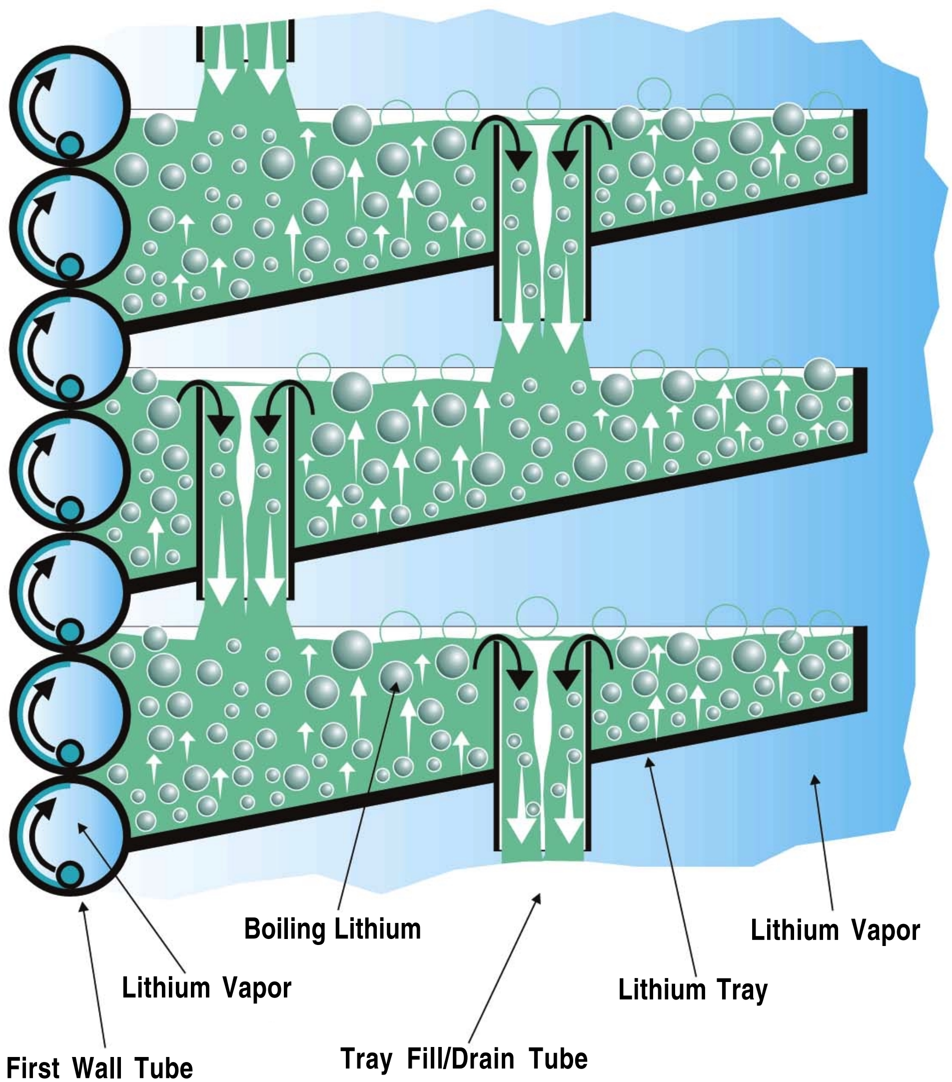
Schematic of EVOLVE First Wall Tubes and Boiling Blanket Trays



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Phase II (FY2000) — We Focused on Evaluating Critical Issues

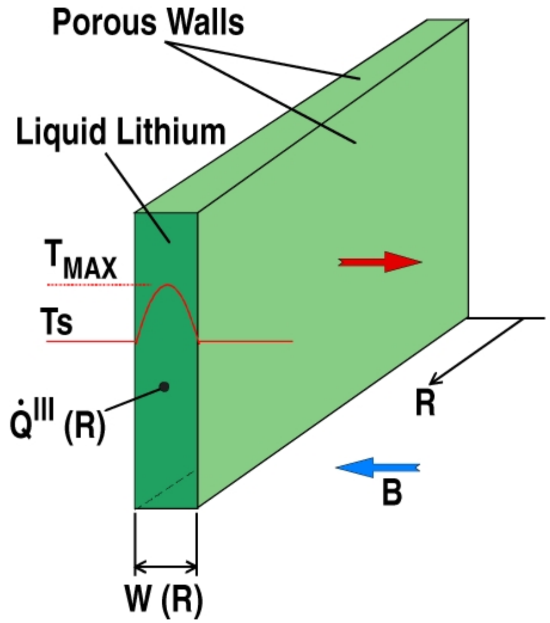
Introduced the Transpiration Blanket and Evaluated:

- First Wall and Blanket Design
- Nuclear Analysis
- Lithium leakage
- Safety

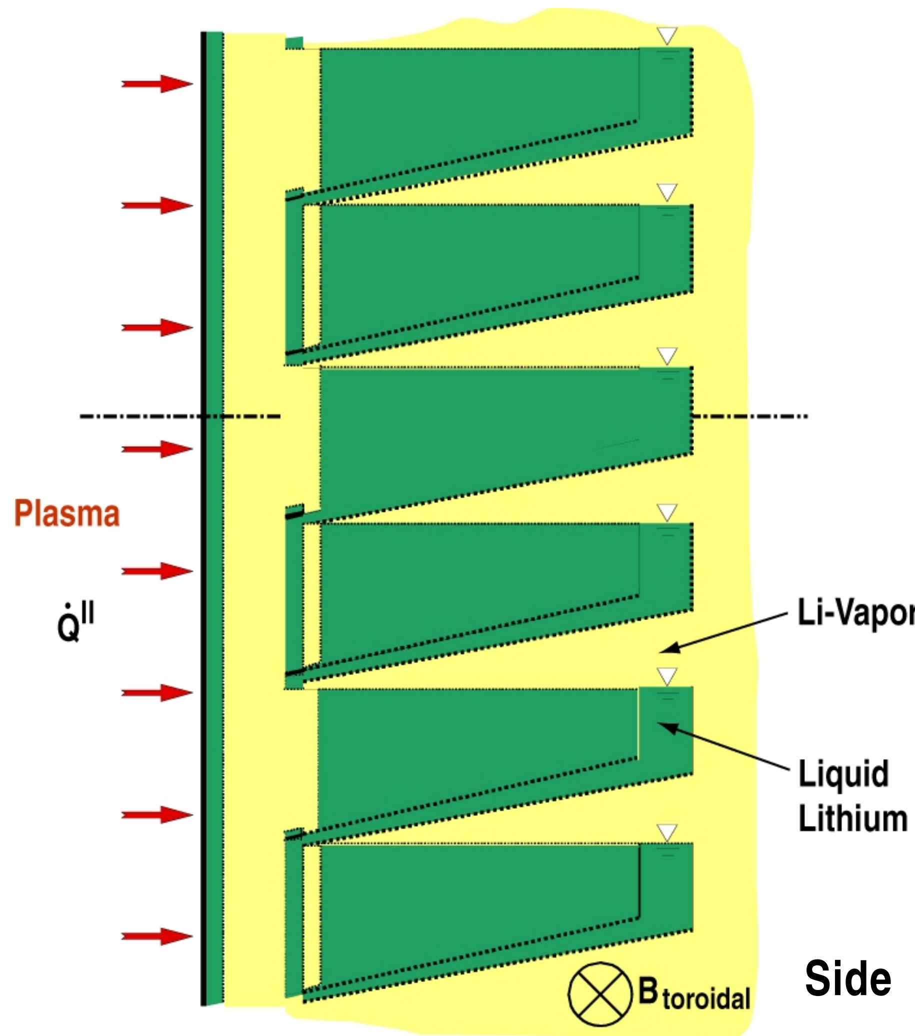
Beginning to address:

- Fundamental liquid lithium experiments
- W-alloy fabrication, testing and experiments

Transpiration Cooled First Wall and Blanket Concept (Poloidal flow FW)



Blanket plate (A)



Side view

(B)

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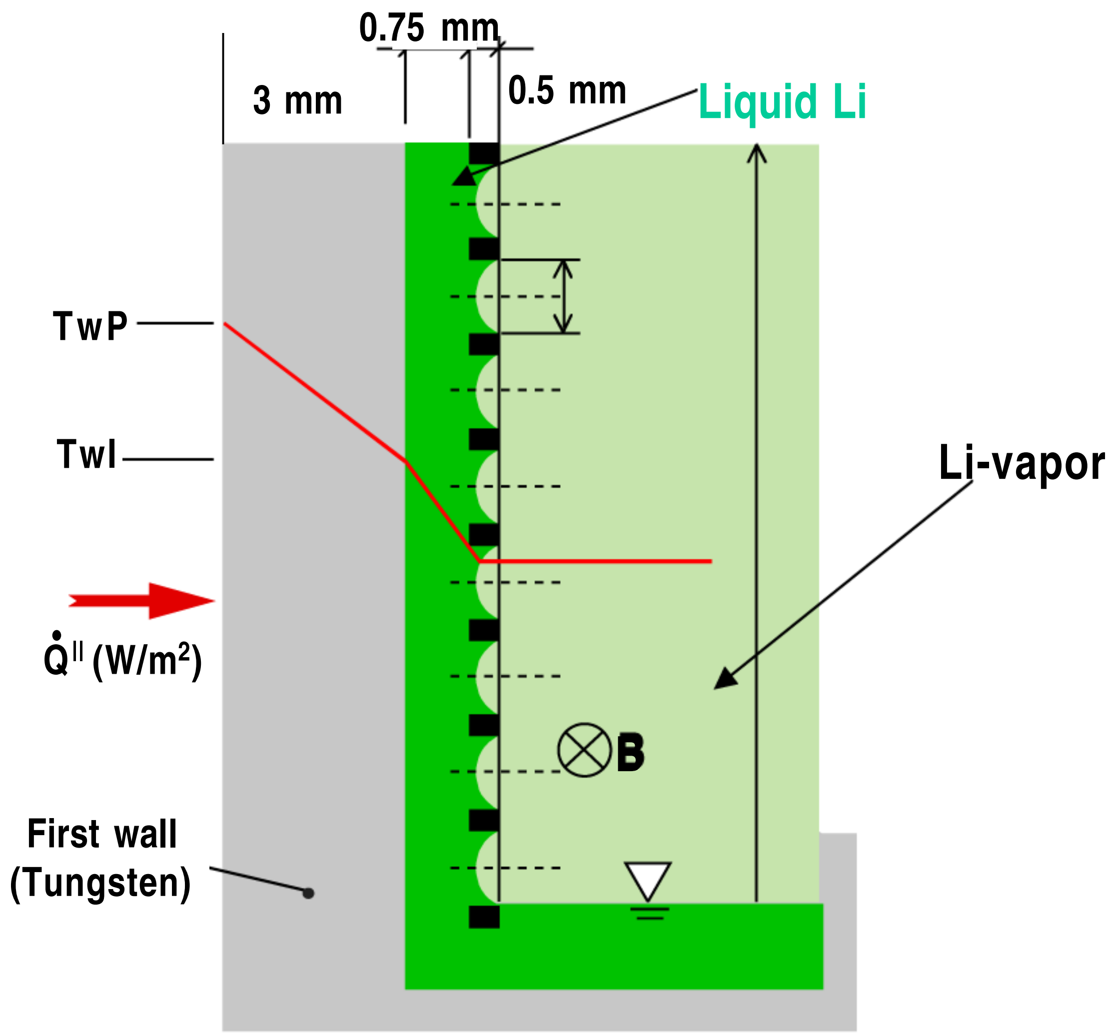
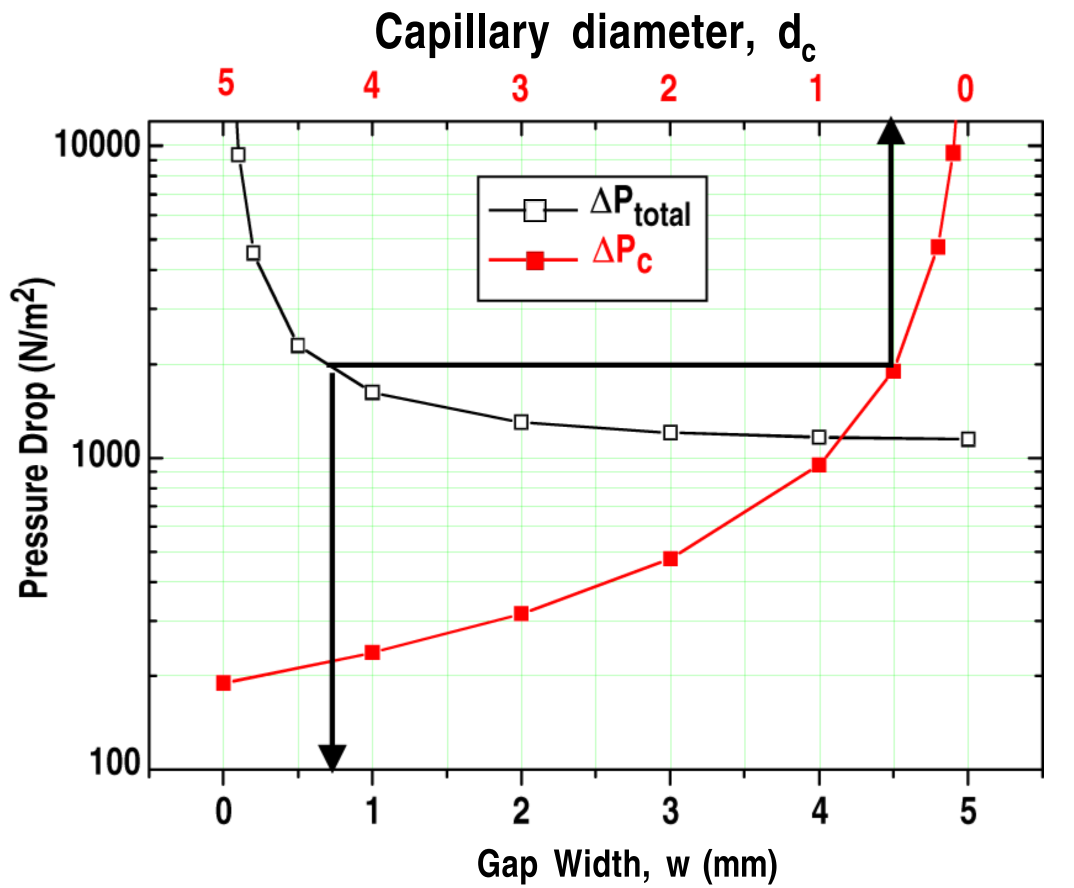
W-alloy First Wall with Capillary and Vaporizing Li



Transpiration First Wall Results

A critical concept for both boiling trays and transpiration cooled blanket options

Design Criteria: Capillary pressure + static pressure > total pressure drop



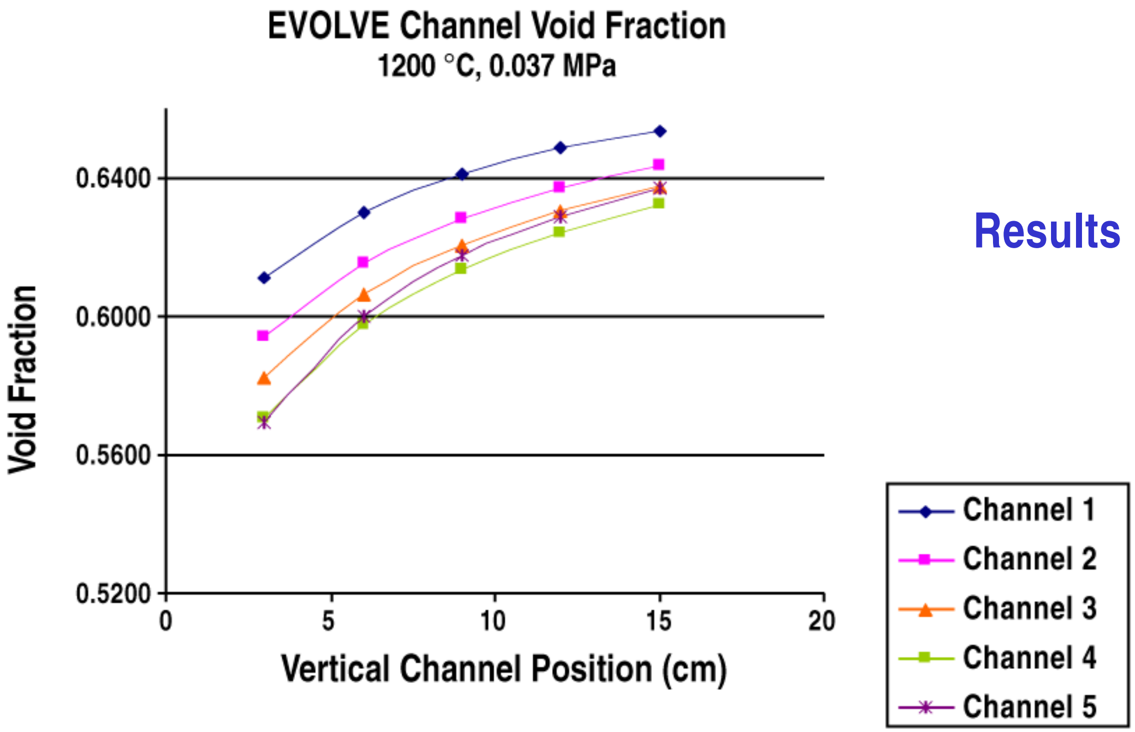
Transpiration FW and Blanket Parameters

FW surface heat flux, MW/m^2	2
Toroidal magnetic field strength, Tesla	6.0
Thickness of the W-alloy FW, mm	3.0
Thickness of the FW screen, mm	0.5
Capillary open area, %	50
Capillary diameter, mm	0.47
Thickness of the blanket W capillary sheet, mm	2.0
Thickness of the FW Li-channel, mm	0.75
True superheating at FW ΔT_{SH}, K	54
Blanket Li slab thickness, cm	3.5-6.9
FW/Blanket Li system pressure, MPa	0.037
ΔP (Capillary + hydrostatic), Pa	3707
ΔP FW/blanket system, Pa	3674
Lithium T_{max}, K	1514
W-alloy T_{max}, K	1597
Li vapor void fraction, %	<10

Lithium Boiling Blanket

Three models for the analysis:

- Neglected magnetic field, applied a standard drift-flux model
- Vapor channel model
- Large B-field effect on boiling



Results from drift-flux model

Radial position
From first wall

Nuclear Analysis

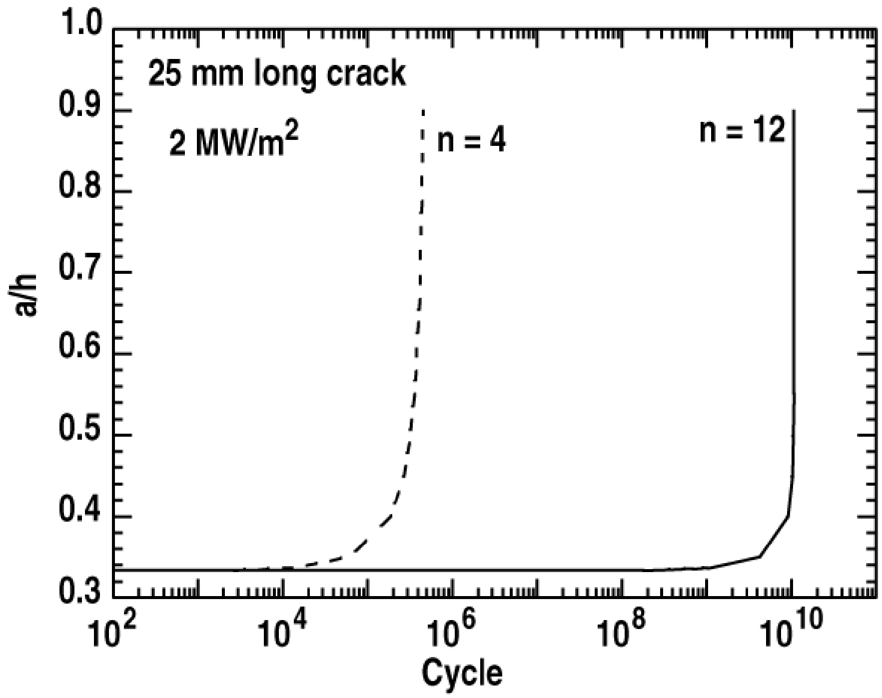
The EVOLVE blanket has excellent nuclear performance

- Applied 1 and 2-D calculations to assess impacts from Li vapor void fraction
- Evaluated cases from 8 to 65% void fraction
- Tritium breeding ratio = 1.33, high void fraction is ~5% lower than low void fraction
- Shielding performance, low void fraction is a factor 2 to 5 better than high void fraction
- IB and OB shielding and radiation damage performance were also assessed
- Afterheat and activation data were provided for safety analysis

Lithium Leakage Assessment

- Fatigue crack can cause fuel dilution and localized heating
- Assumed crack size 25 mm long, 10 micron wide, Li pressure @0.17 Mpa >>0.04 MPa
- Results show:
  Li leakage rate
  5×10^{-4} g/s << 0.2 g/s (heat removal rate)
  Fuel dilution
  10^{17} atoms /m^2/s << 2×10^{20} atoms/m^2/s

Based on Present W-alloy Data
Crack Growth May Not Be A Significant Concern



- Crack depth vs. cycle for an initially 25 mm long, 1 mm deep crack (a_0) subjected to 2 MW/m^2 wall thickness h = 3 mm, crack growth calculated using n =4 and n = 12

where $$\frac{da}{dN} = 7x10^{-27}(\Delta K)^n$$

ΔK — stress intensity factor

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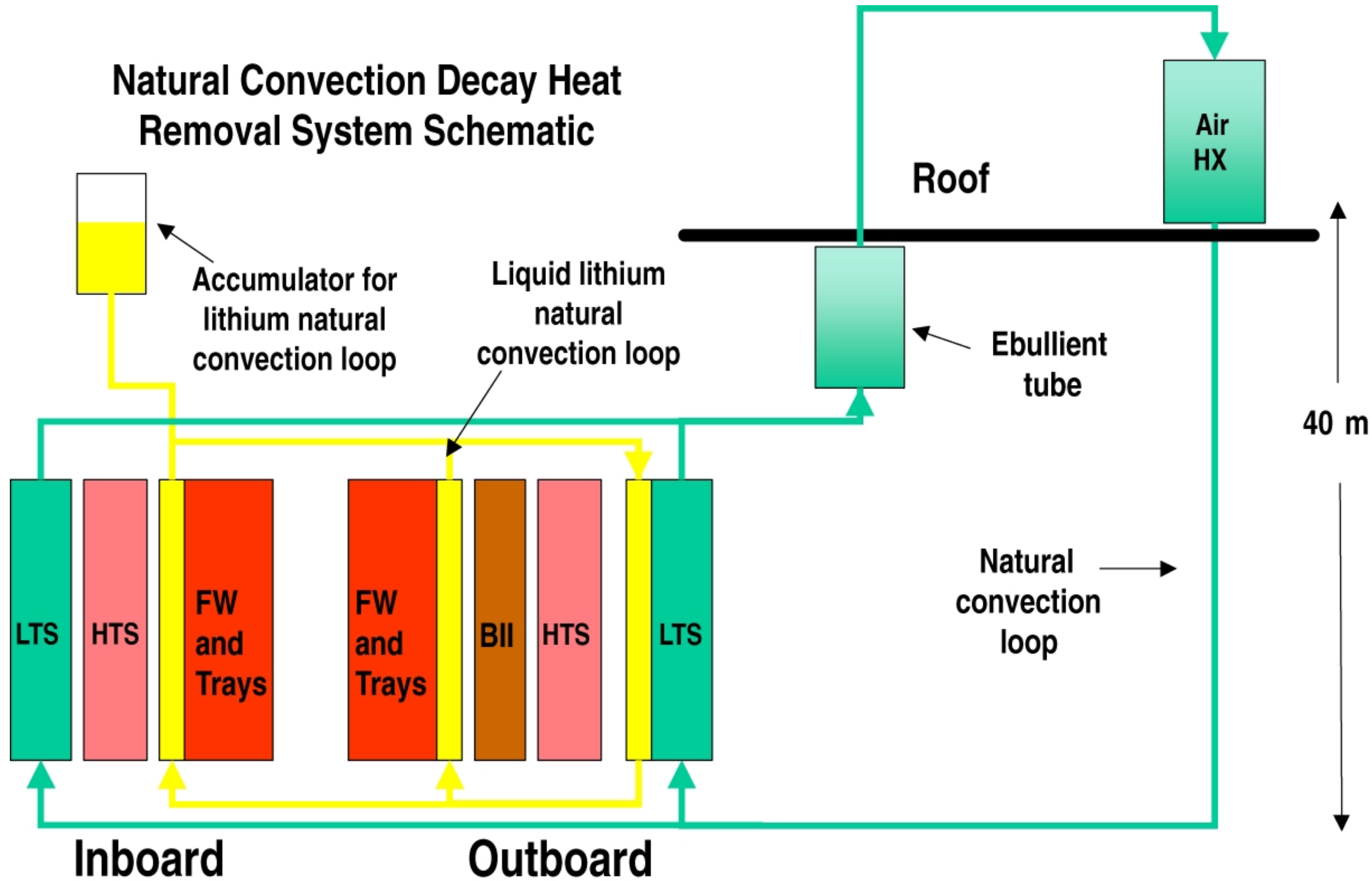
Safety-afterheat removal

Multiple natural- convection loops passive heat removal



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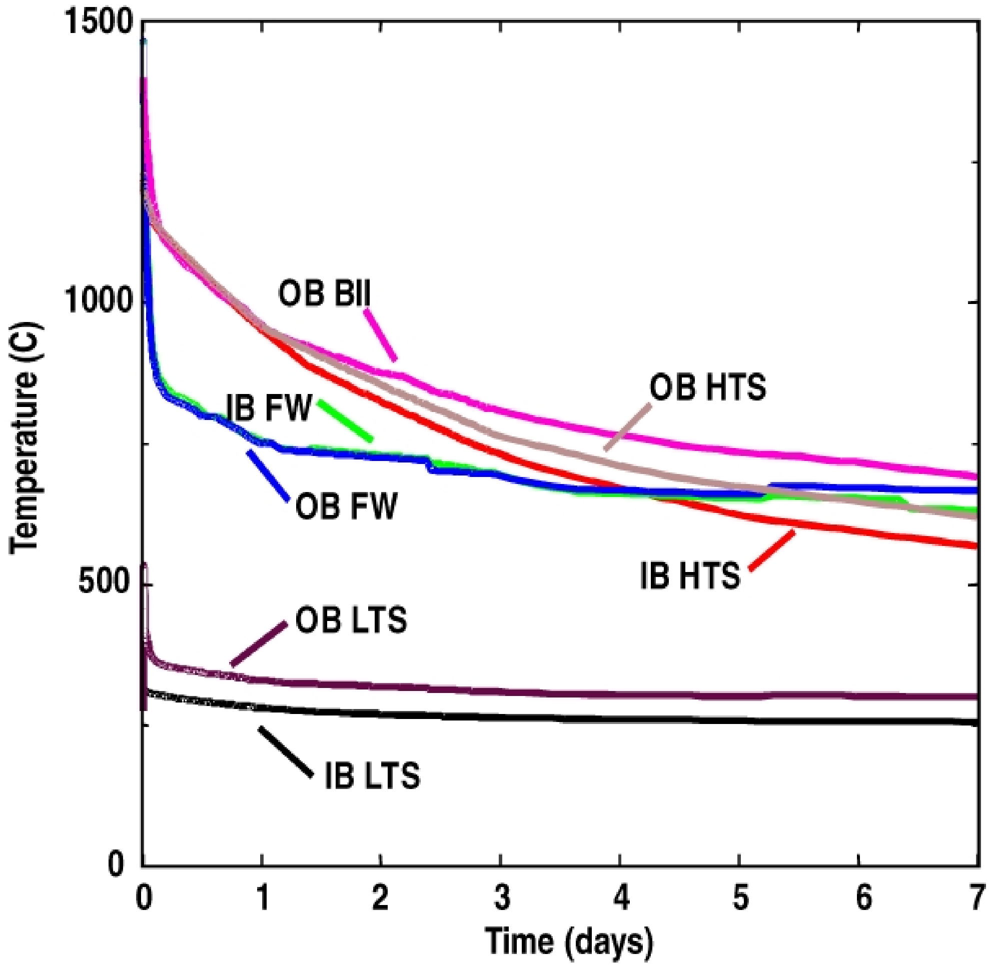
Evolve component surface temperatures during a complete loss of power accident scenario



First wall T <800°C in 13 hours

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The Safety Goal of No Public Evacuation Plan Could Be Satisfied

- Mass mobilization calculation with 375 kg of W-alloy aerosol (95% is vented in 2–3 days)
- With HVAC filter in place, a long response time of 1.6 days is available for the W-dust+HTO release to be < 10 mSv limit

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W Component Fabrication

- Piggyback on the development of helium-cooled W-alloy components, SBIR programs
- Thermacore built a W porous metal heat exchanger with W end cap in 4 separate assembly-brazing steps, all using BAu-4 (Nioro-TM) braze filler metal, either 0.01 or 0.02 inch diameter wire in dry hydrogen, tested to heat flux>5 MW/m^2, using 20°C helium at 4 MPa
- Fabrication of W-alloy components has been very difficult, and significant further research and progress will be needed

We Have Higher Confidence in the Credibility of the EVOLVE Concept

- We have assessed areas of:
  - FW/blanket thermal-hydraulics
  - Nuclear design
  - FW leakage
  - Passive afterheat removal
  - Accidental releases

- High performance and passively safe design has been shown to be credible

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Critical Issues and Key Inputs Needed Have Been Identified:

- Un-irradiated and Irradiated properties of W-alloys (e.g. W-5Re, W-La_2O_3, and TiC nano doped) needed for future selection
- Transpiration cooled W-alloy FW is crucial to transpiration-cooled and boiling blanket options. Reliability of W capillary screen will have to be demonstrated
- Experiments are needed to quantify Li superheat from a surface and bulk lithium, and to provide understanding on the search for stable boiling regime of lithium in a magnetic field
- Technique of W-alloy component fabrication has been initiated but much more development will be needed