Taming The Plasma Material Interface

Issues, Gaps, Research Needs

ReNeW Workshop

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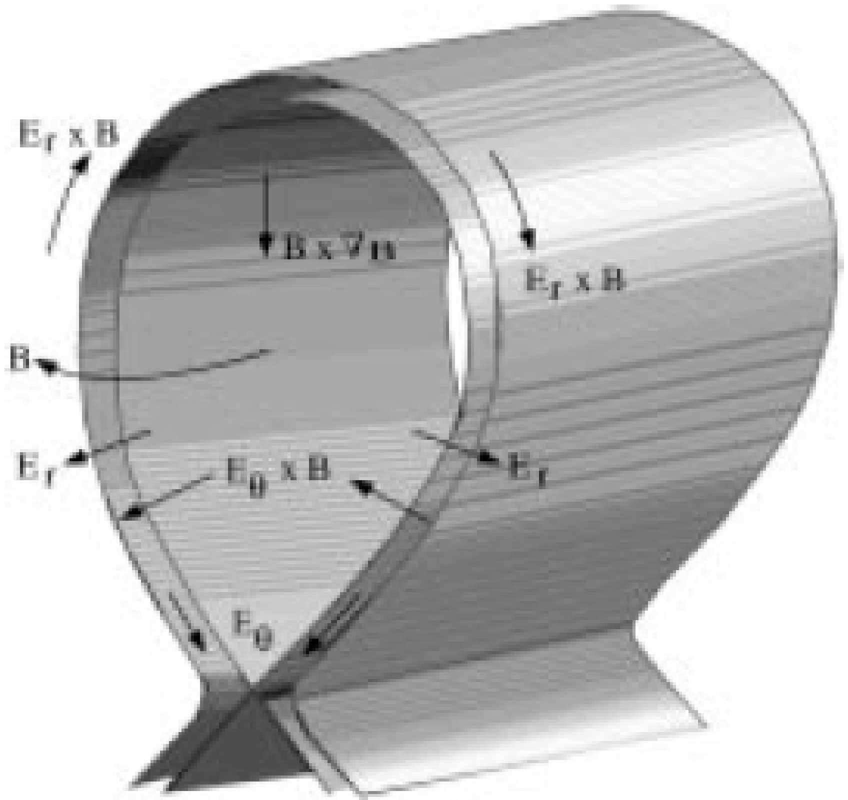
Outline

- Review of Greenwald Panel Issues
- Summary of Research Needs
- Research Thrusts Driven by Needs

Greenwald Panel Issues for PMI

- **I8. Plasma-Wall Interactions:** ***Understand and control of all processes which couple the plasma and nearby materials.***
- **I9. Plasma Facing Components:** ***Understand the materials and processes that can be used to design replaceable components which can survive the enormous heat, plasma and neutron fluxes without degrading the performance of the plasma or compromising the fuel cycle.***
- **I10. RF Antennas, Launching Structures and Other Internal Components:** ***Establish the necessary understanding of plasma interactions, neutron loading and materials to allow design of RF antennas and launchers, control coils, final optics and any other diagnostic equipment which can survive and function within the plasma vessel.***

Complex Forces Act in the Scrape-Off Layer



- Radial Electric fields & Gradients of B
- Neutral particle influx and Impurity generation from the PFCs
- Several new phenomena have been discovered that alter our understanding of the SOL.
- The SOL is poorly diagnosed which causes large uncertainty in conditions at PFCs

Illustration from P. Stangeby, "Physics of the Boundary Plasma"

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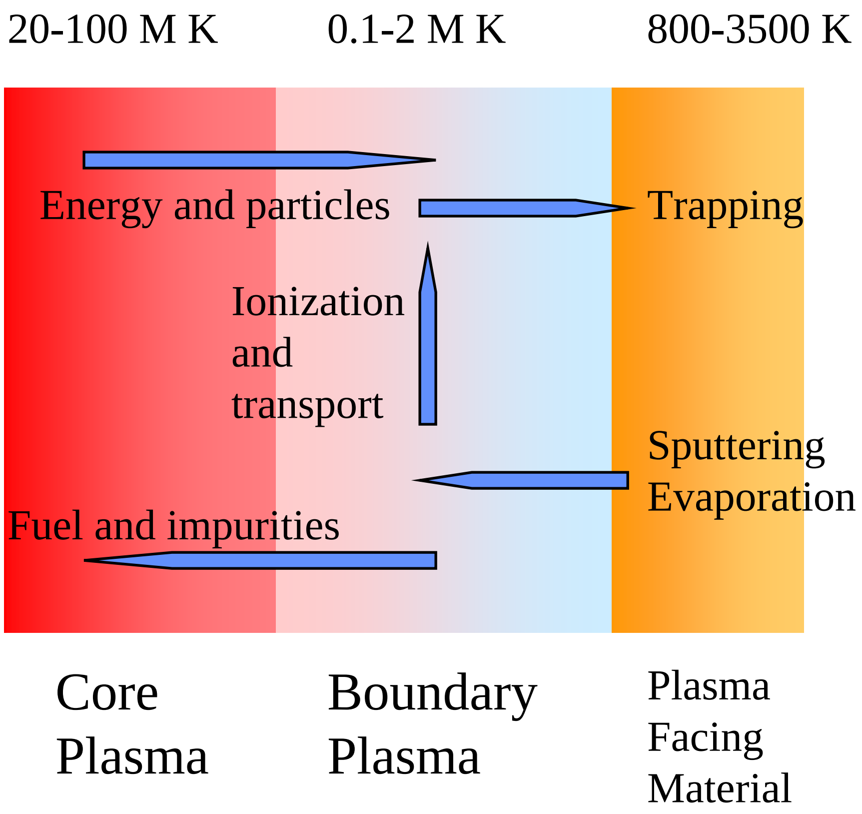
Research Needs for PWI I

The uncertainties in the SOL have driven ITER design to the edge of the possible

- **Diagnostic investments required to identify missing physics controlling plasma wall interactions-understanding the plasma edge, scrape-off layer, and near-surface.**
- **More dedicated plasma time for edge measurements and plasma conditions aimed at sorting out key edge issues (e.g. power scaling).**
- **Creating a more comprehensive SOL database for testing plasma edge models.**
- **Improvements needed to basic edge/SOL PWI plasma model/code components**
- **Code development to improve coupling among neutral transport, plasma transport, impurity transport, and overall material response-yielding predictive PWI/SOL capability.**

Fusion Plasma Surface Interactions

- The core plasma must be kept clean of impurities and He ash
- The plasma facing component surface sees high density and temperature plasma
- Key issues are hydrogen trapping, erosion, and thermal fatigue
- Spans science specialties from ionized gases to materials science



Status of PSI

- Fundamental studies of PWI have led to understanding of phenomena like chemical erosion, radiation enhanced sublimation, and hydrogen retention in carbon.
- A variety of wall conditioning techniques are applied to achieve high performance plasmas
- Recent studies of W have revealed new phenomena like formation of nano-scale fuzz under some plasma conditions.
- Transport of eroded material is poorly understood

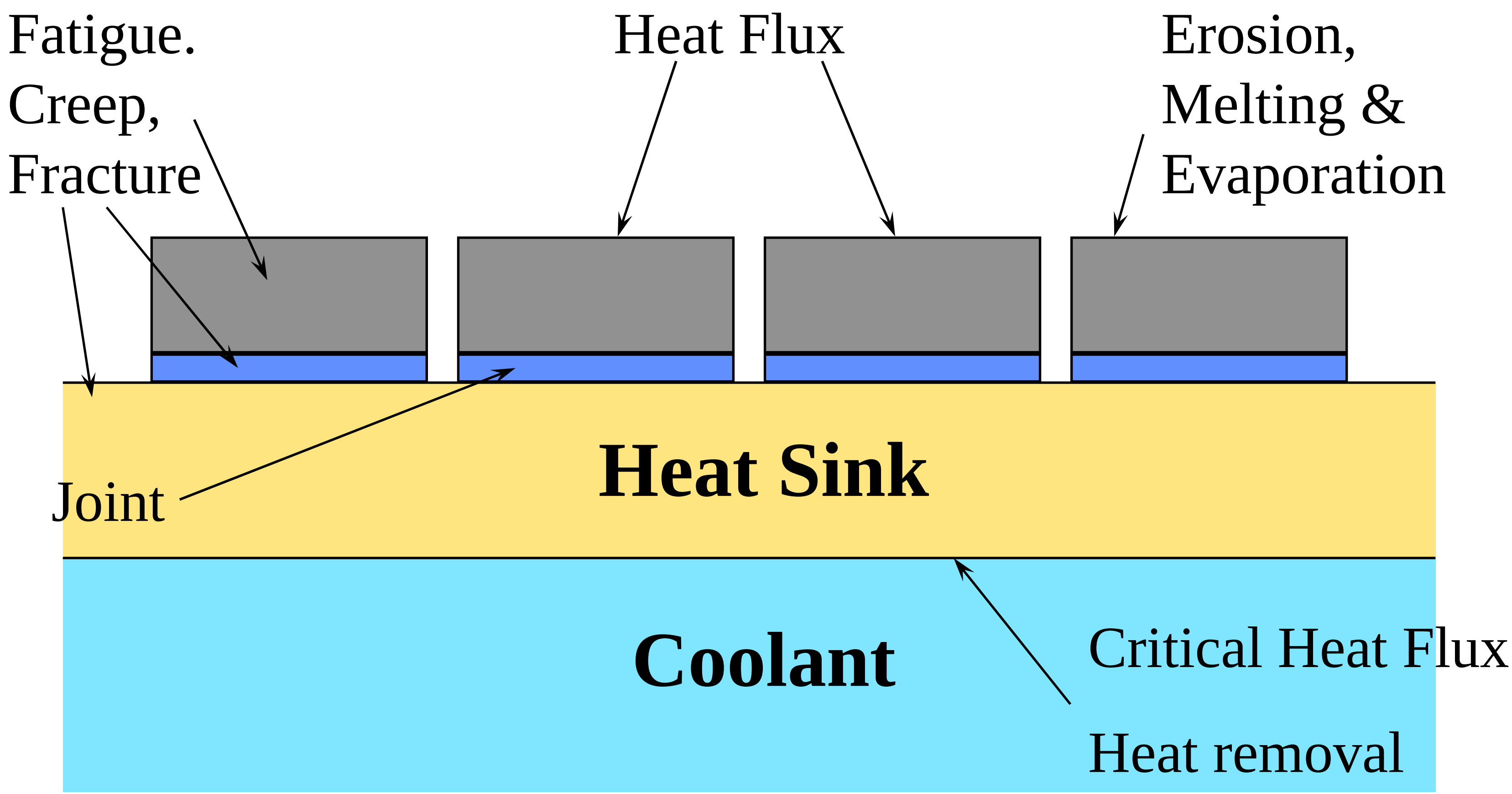
Research Needs for PWI II

- PWI Science studies needed for future machines will require a suite of improved or new laboratory plasma machines compatible with high temperature samples.
- Test devices dedicated to study of RF coupling to SOL plasma and the modification of the SOL by RF are needed to create the database needed to develop and validate models of the SOL that include RF effects

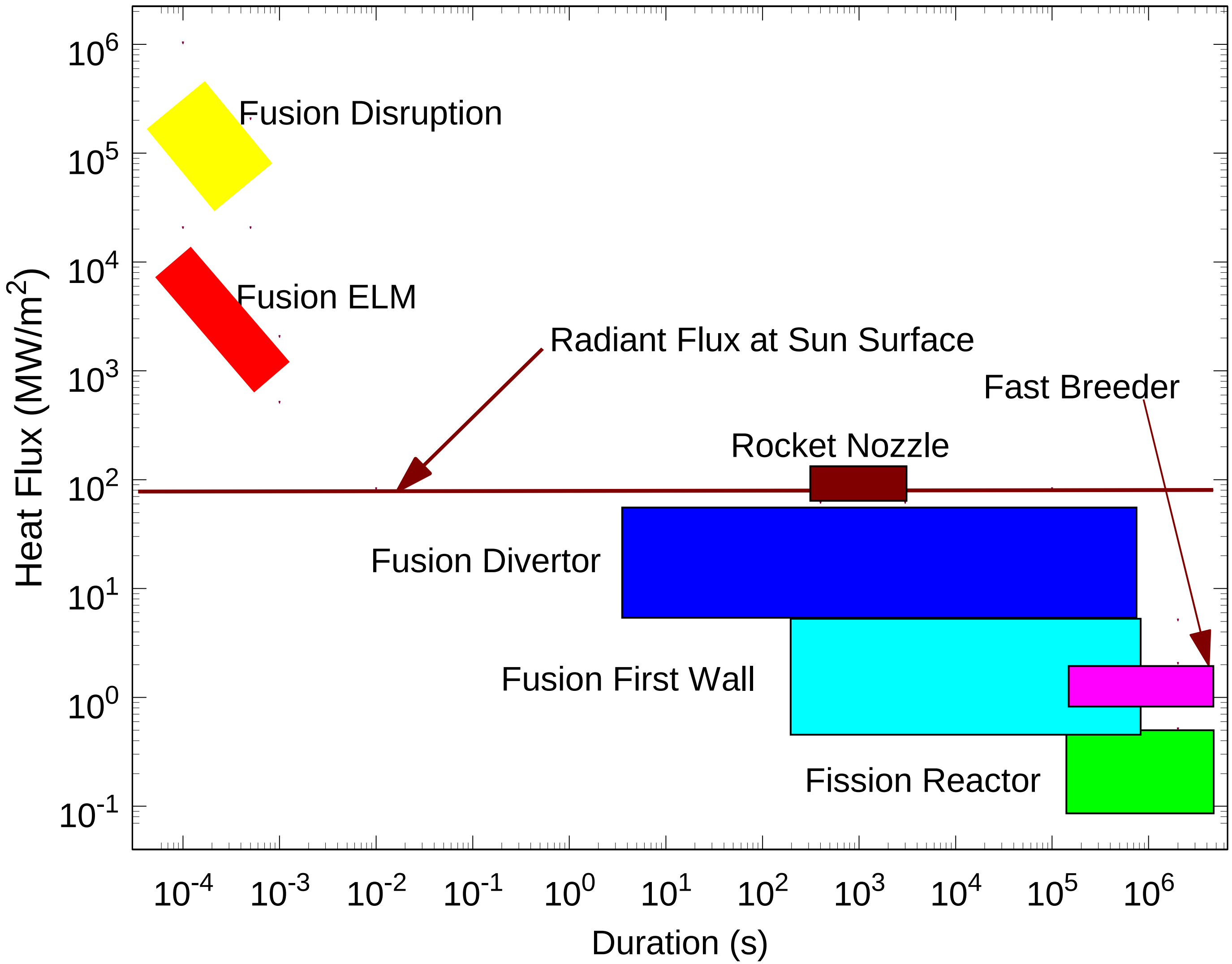
Research Needs for PWI III

- Innovative divertor development to solve the plasma heat-flux problem.
  - Novel magnetic configurations such as the super-X divertor.
- Elimination or control and mitigation of transients, long pulse, and elevated temperatures on PWI.
  - Collaboration with core physics and PMI studies and PFC research.

Plasma Facing Components



Magnetic Fusion Energy Heat Fluxes



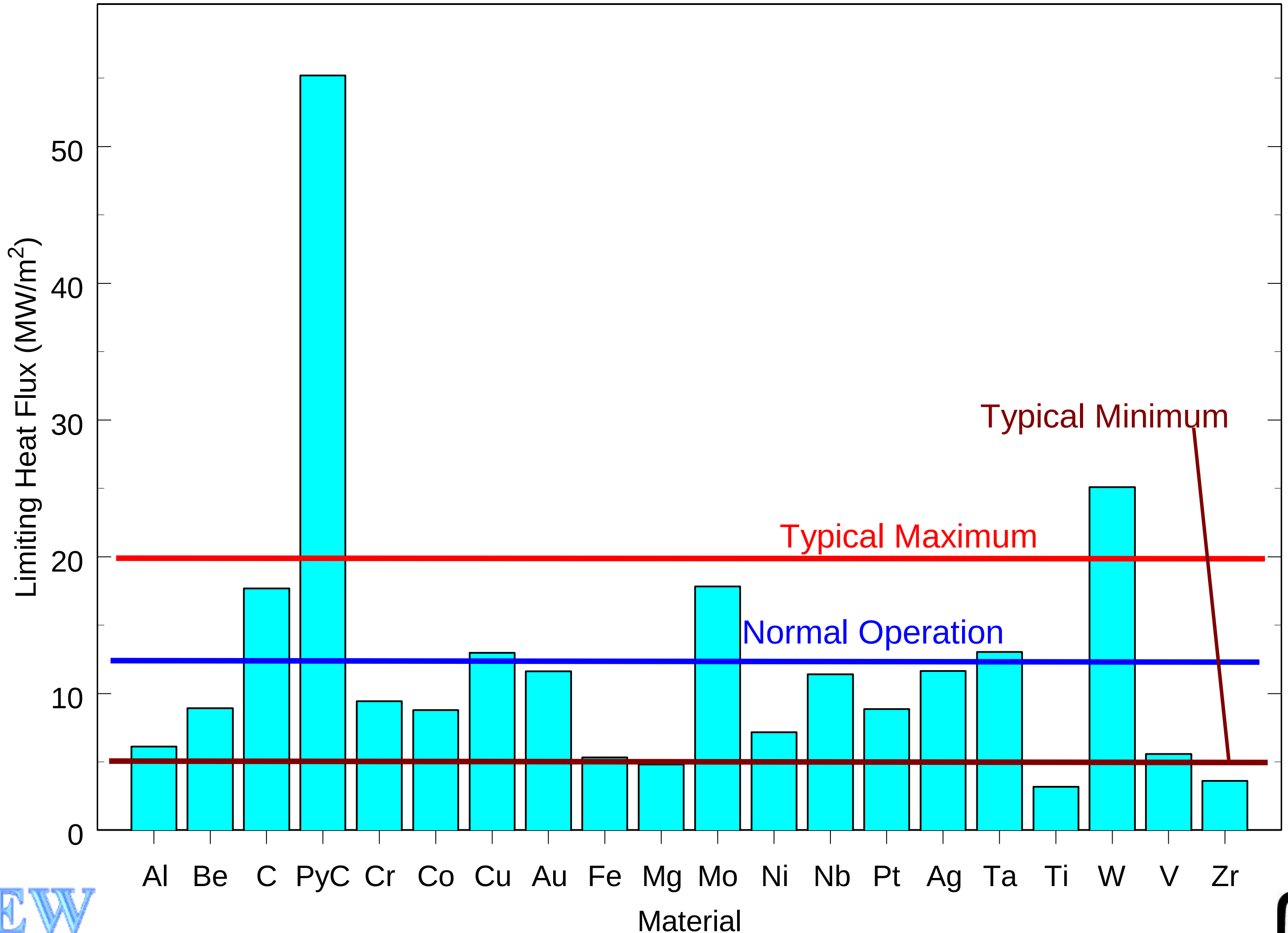
Status of PFC Science

- **Actively water cooled PFCs have been developed for ITER.**
- **Extensive cyclic heat flux testing of ITER PFCs has been completed and the components are nearly qualified.**
- **Irradiation of ITER materials has been conducted but no integrated component irradiation has been done.**
- **Development of solid or liquid PFCs for future devices is just starting.**

Research Needs for PFC I

- **Development of robust helium-cooled solid surface PFCs to withstand steady state maximum surface loading of 10 MW/m^2**
- **Development of PFCs compatible with innovative magnetic configurations (Super-X, stellarator, …)**
- **Development of solid surface PFCs that are resistant to off-normal events.**
- **Development of innovative refractory materials with high thermal conductivity compatible with He coolant or liquid surfaces.**

Heat Flux Capability



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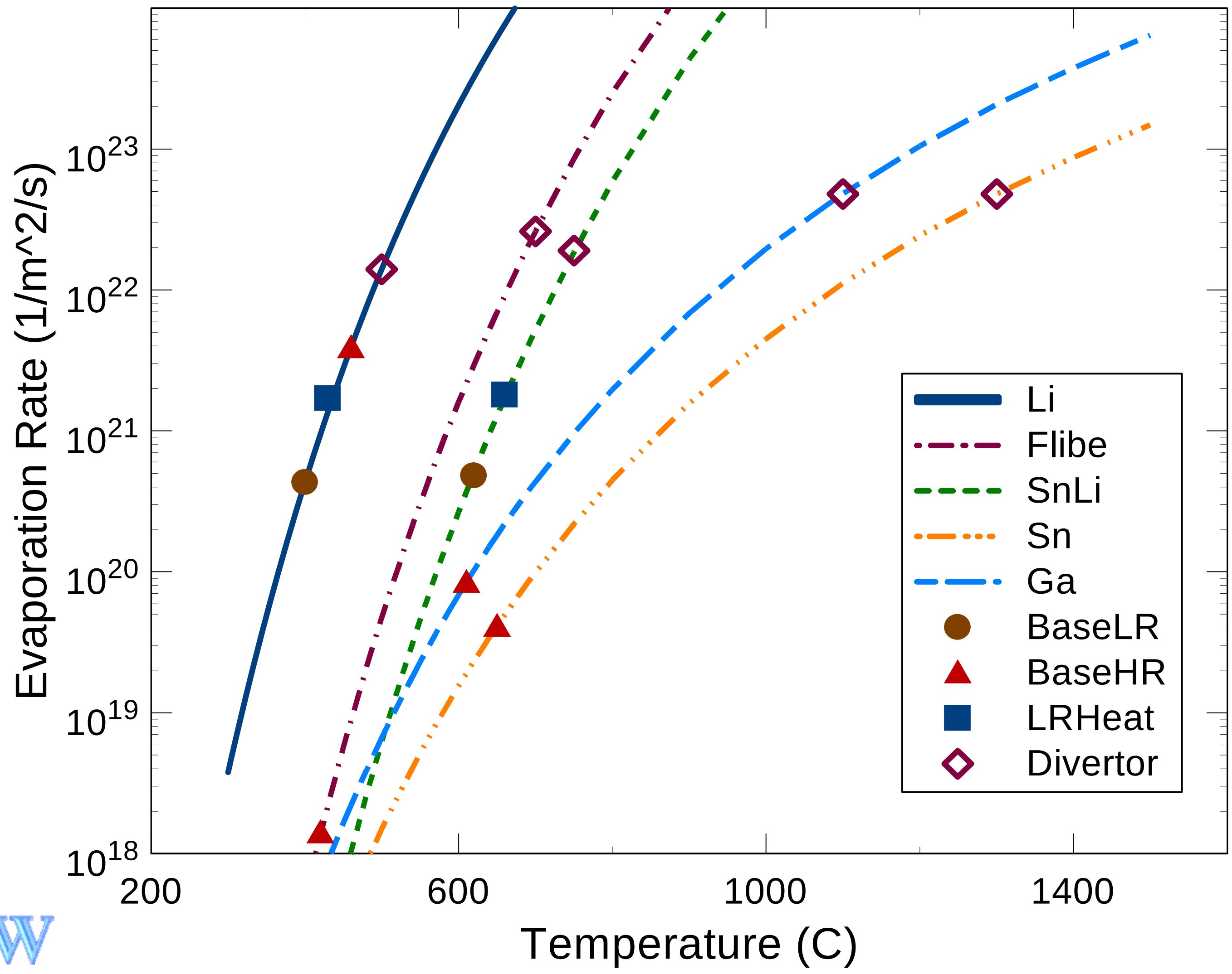
Research Needs for PFC II

- Development of high heat removal capacity refractory Helium cooled heat sinks (including joining methods).
- Improved or new facilities for laboratory testing of innovative PFCs.
- Fusion device testing of innovative PFCs in a non-nuclear environment.
- Development of a database on nuclear irradiation effects on the above.
- Integrated testing of innovative PFCs in a fusion nuclear environment.

Temperature Limits



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Research Needs for PFC III

- MHD modeling at high Hartmann and Reynolds numbers with fusion relevant fields and gradients
- Creative engineering of practical devices for injecting, controlling and removing liquid material
- Laboratory testing of liquid surface PFCs in relevant magnetic conditions with heat and particle flux.
- Liquid surface option operation in a tokamak environment
- Innovative design for high thermal performance liquid surface option

Status of Internal Components

- Some ITER diagnostics require components that are exposed to the plasma like mirrors. Design of those components has proven challenging for ITER.
- RF antennas and launchers similar to those for ITER are being tested on machines like JET.
- Internal coils for ELM or RWM control have proven effective on existing machines. Late inclusion of such coils in ITER is a major complication in the design of PFCs.

Research Needs for IC I

- Identify and develop creative, *new* diagnostic techniques that are compatible with the burning plasma environment.
- Development of innovative measurement techniques able to be fully extrapolated to *post-ITER* devices.
- Creative solutions need to be developed to the in-vessel diagnostic component problems (plasma facing optical components)
- Places to test these diagnostics will be needed.

Research Needs for IC II

- **Reliable and verified techniques for computing self-consistent heat and particle fluxes to high-power, energized components (RF antennas, etc) which interact with and alter the edge plasma.**
- **Modeling results need to be validated. Some modeling components can be validated on Test Stands.**
- **Final testing and validation of the modeling efforts will require significant operational time on a confinement experiment.**
- ***Verified 3-D design concepts and techniques for cooled internal components.***
- ***Explore new concepts that move the sensitive EC launcher components away from the influence of the plasma edge.***

Research Needs for IC IV

- Enhanced theory, modeling, and diagnostic support, and additional 3D coils systems on existing, upgraded, and future facilities to understand the plasma response to 3D fields
- A systematic comparison of near and far-away coils systems with a full assessment of the engineering and physics trade-offs.
- Exploration and development of coil/insulator technologies that can survive the nuclear environment.
- Understanding of the interaction between 3D coils and any permeable ferritic materials in inserts or blanket modules near the plasma edge.
- Assessment of a wider range of uses and implications of 3D coils (including runaway suppression and 3D heat loads on PFCs).
- Exploration of the methods to extract the heat generated in 3D coils from ohmic losses and nuclear heating (feasibility to function at temperature above 600°C).

Research Thrusts for PWI

Research Thrust	Description
9	Unfolding the Physics of the Boundary Layer Plasma
10	Understanding and Developing Plasma Materials Interaction Science and Technology
11	Innovations for Improved Power and Particle Handling
12	Demonstrate an Integrated Solution for Plasma-Material Interfaces

Taming Plasma Material Interactions