Taming The Plasma Material Interface

Summary of Thrusts

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Outline

- **Summary of Issues**
- **Four thrusts to bridge the gaps**

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.*

Thrust Titles

9. Unfolding the Physics of the Boundary Layer Plasma
10. Decode and Advance Plasma Material Interface Science and Technology
11. Improve Power Handling through Engineering Innovation
12. Demonstrate an Integrated Solution for Plasma-Material Interfaces Compatible with an Optimized Core Plasma

Thrust 9 Key Issues

- ***How can we fully identify and characterize the physics controlling the boundary layer and resulting plasma-wall interaction sufficiently for physics-based scaling to future devices?***
- ***How can we accurately describe the highly turbulent boundary layer plasma with material erosion in comprehensive simulations to create simplified models?***
- ***How can the predictive capability of plasma edge modeling including material interaction with internal components be improved?***
- ***How can the magnetic configuration of the boundary region be modified to spread out the heat flux at the material interface?***

Thrust 9 Actions

- Develop and deploy new diagnostics in existing devices for comprehensive boundary layer measurements of plasma flow, density, temperature, electric field, turbulence characteristics, and neutral density in at least 2D and 3D, to provide the data necessary to uncover the controlling physics.
- Increase level-of effort on validation of individual edge turbulence and transport codes, then expand this effort to involve more comprehensive boundary layer models.
- Develop measurements and predictive capability of the plasma fluxes to RF antennas and launchers; develop models for the self-consistent modification of the boundary layer plasma by the RF wave injection and other internal components.
- Design and implement innovations of the boundary magnetic geometry in existing devices to demonstrate optimized plasma heat exhaust that is within material limits, and design/implement such a configuration in a future fusion device.

Thrust 10 Key Issues

- Can we reliably extrapolate conditions at the wall of today's pulsed confinement machines to future steady-state reactors?
- Can we develop clever new concepts to extend the wall operational limits?
- Is it possible to predict the impact of this evolution on an equilibrium plasma state and on plasma facing component lifetime during steady-state operation? Can more resistant materials and coatings suitable for use in diagnostics, or high power radio frequency and microwave components, be developed?

Thrust 10 Actions

- Upgrade existing laboratory facilities and test stands, and build new facilities capable of extending PSI parameters closer to conditions expected in fusion reactors, including the capability to handle tritium, liquid metals, and irradiated materials
- Build large-size test stands where full-scale internal component tests and design validations can occur
- Develop and improve first principle models of the material and plasma coupling for future fusion machines by validating against new experimental data
- Invest in surface material diagnostics to quantify material behavior and evolution
- Develop and test new surface materials to improve performance margins

Thrust 11 Key Issues

- How do we develop better PFC designs that operate at higher temperatures and can remove higher heat loads with adequate design margin? Can we exploit larger area targets with smaller inclination angles (<1°) and obtain better alignment to the magnetic flux surfaces?
- How do we develop innovative solid PFCs from new low activation alloys and assemble the necessary database for liquid PFCs? Is it possible to develop new components that are radiation tolerant while having minimal impact on the plasma during quiescent and transient plasma operation?
- How do we study synergistic effects of irradiation damage and tritium permeation for solid and liquid PFCs?

Thrust 11 Actions

- Design, fabricate and test refractory heatsinks with advanced cooling techniques for high temperature operation (>600C) and deploy liquid metal PFC experiments in plasma devices.
- Develop fabrication processes and better joining techniques using reduced activation refractory alloys for both PFCs and internal components, e.g. RF launchers.
- Construct/upgrade new lab facilities for synergistic testing including cyclic high-heat-flux, irradiation/permeation, and liquid metal performance; and improve models of thermal performance, irradiation damage and tritium transport in PFCs.
- Provide improved PFCs for qualification on existing or new confinement experiments..
- Develop more robust PFCs for transient events with higher design margins and improved reliability and maintainability. Include engineering diagnostics to monitor PFC performance and provide data for lifetime prediction models.

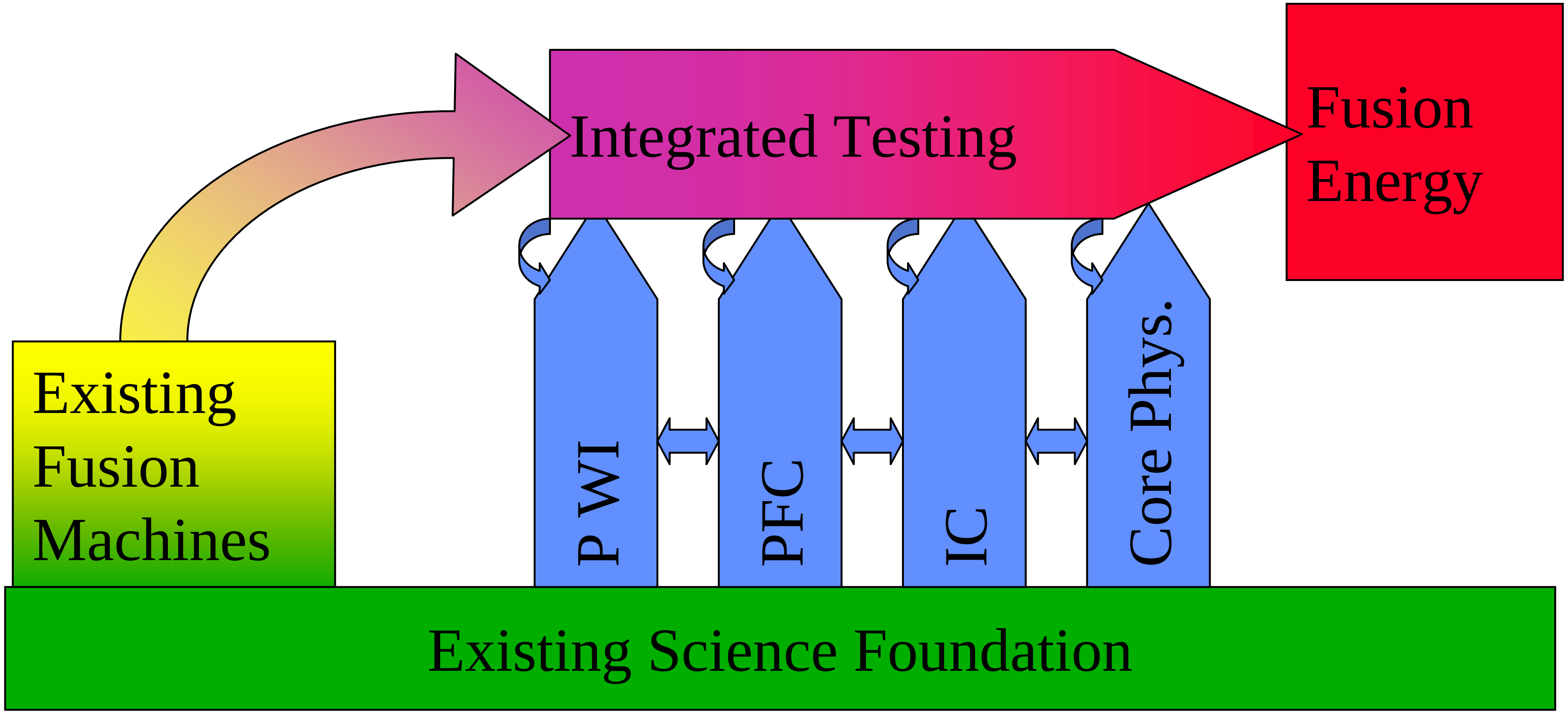
Thrust 12 Key Issues

- **What techniques for limiting both steady and transient heat flux to surfaces are compatible with optimized core and boundary plasma performance?**
- **How can material erosion, migration and dust production from plasma-facing surfaces be made compatible with long-term operation and core plasma purity?**
- **How can plasma-facing materials and configurations be optimized at elevated temperature for fuel recycling and plasma interactions?**
- **How can hydrogenic fuel retained in materials be reduced to acceptable levels?**
- **What techniques are simultaneously compatible with core plasma sustainment and edge plasma power handling requirements?**

Thrust 12 Actions

- Develop design options for a new facility with a DEMO-relevant boundary to assess core-edge interaction issues and solutions. Key desired features include high power density, sufficient pulse length and duty cycle, elevated wall temperatures, as well as steady-state control of optimized core plasma.
- Investigate a non-nuclear environment, with hydrogen and deuterium fuel, to assure flexibility in changing boundary components as well as comprehensive measurements to fully characterize the boundary plasma and plasma-facing surfaces. The balance of hydrogen and deuterium operation should be part of the design optimization.
- Construct a moderate scale, non-nuclear facility focused on understanding and optimizing integrated solutions to the coupled core-edge challenges described above. It would build on and contribute to transient heat flux control from Thrust 2, plasma control and sustainment from Thrust 5, boundary plasma models from Thrust 9, plasma-material interaction science from Thrust 10 and plasma-facing component technology from Thrust 11.

Taming Plasma Material Interactions



Existing Fusion Machines

Integrated Testing

Fusion Energy

P WI

PFC

IC

Core Phys.

Existing Science Foundation

RENEW

Sandia National Laboratories