Plasma Facing Component Science and Technology for Burning Plasma Experiments

December 11-13, 2000

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Presented at the UFA Burning Plasma Workshop

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for the United States Department of Energy under contract DE-AC04-94AL85000.

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Outline

- Burning plasma device designs
- Pulse length issues
- Plasma Facing Component (PFC) issues
- Plasma core to scrape-off layer and divertor coupling
- Tritium issues
- Materials Science issues
- Conclusions

Burning Plasma Device Designs

- Numerous design options for a burning plasma experiment have been examined over the last ten years.
- The sizes vary from <2 m to > 8m.
- The pulse lengths vary from a few 10's of seconds to 1000's of seconds (even steady state).
- By numerous measures of performance these devices exceed the capabilities of existing devices (P/R, P/A, fluence, A/V, etc.)

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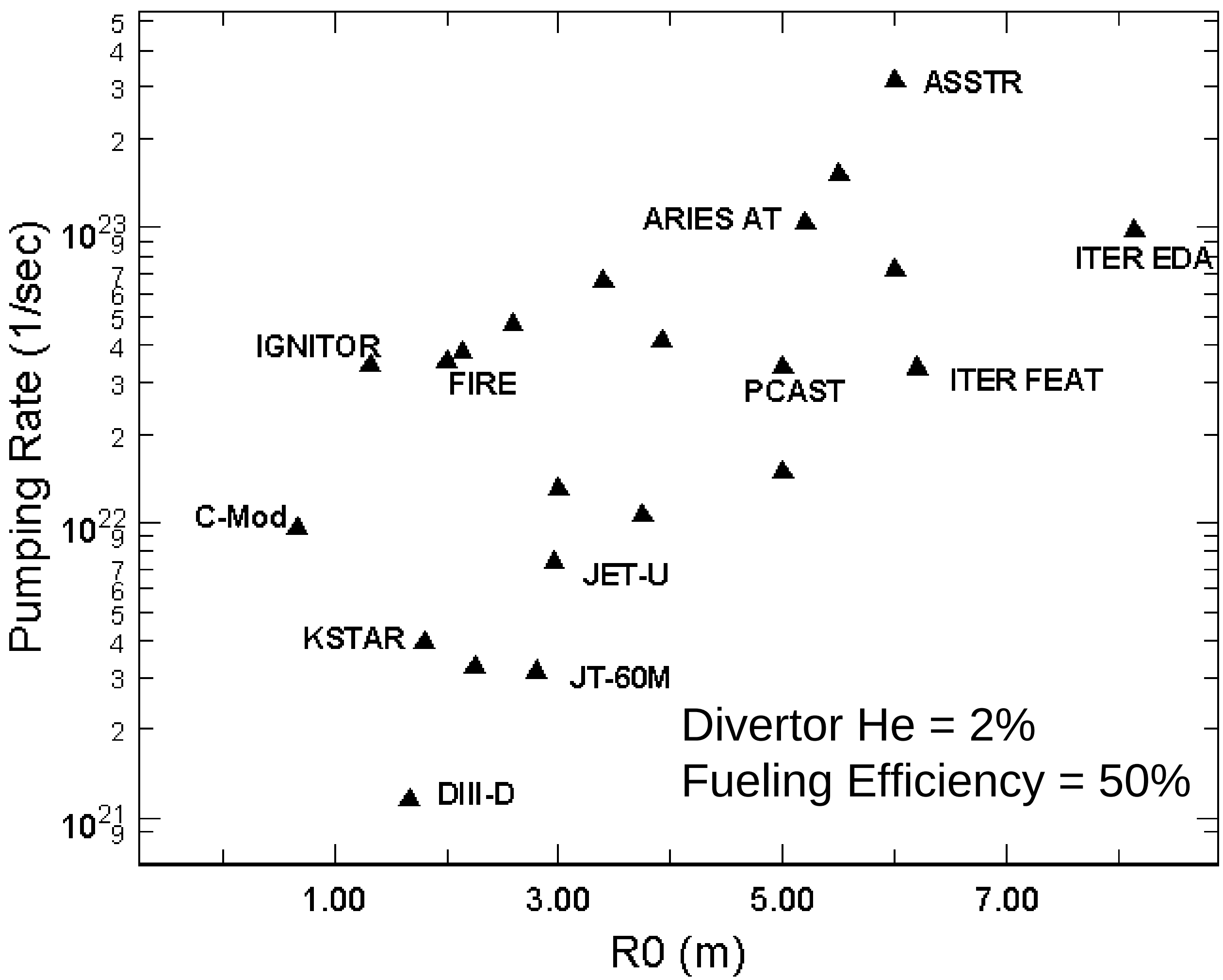
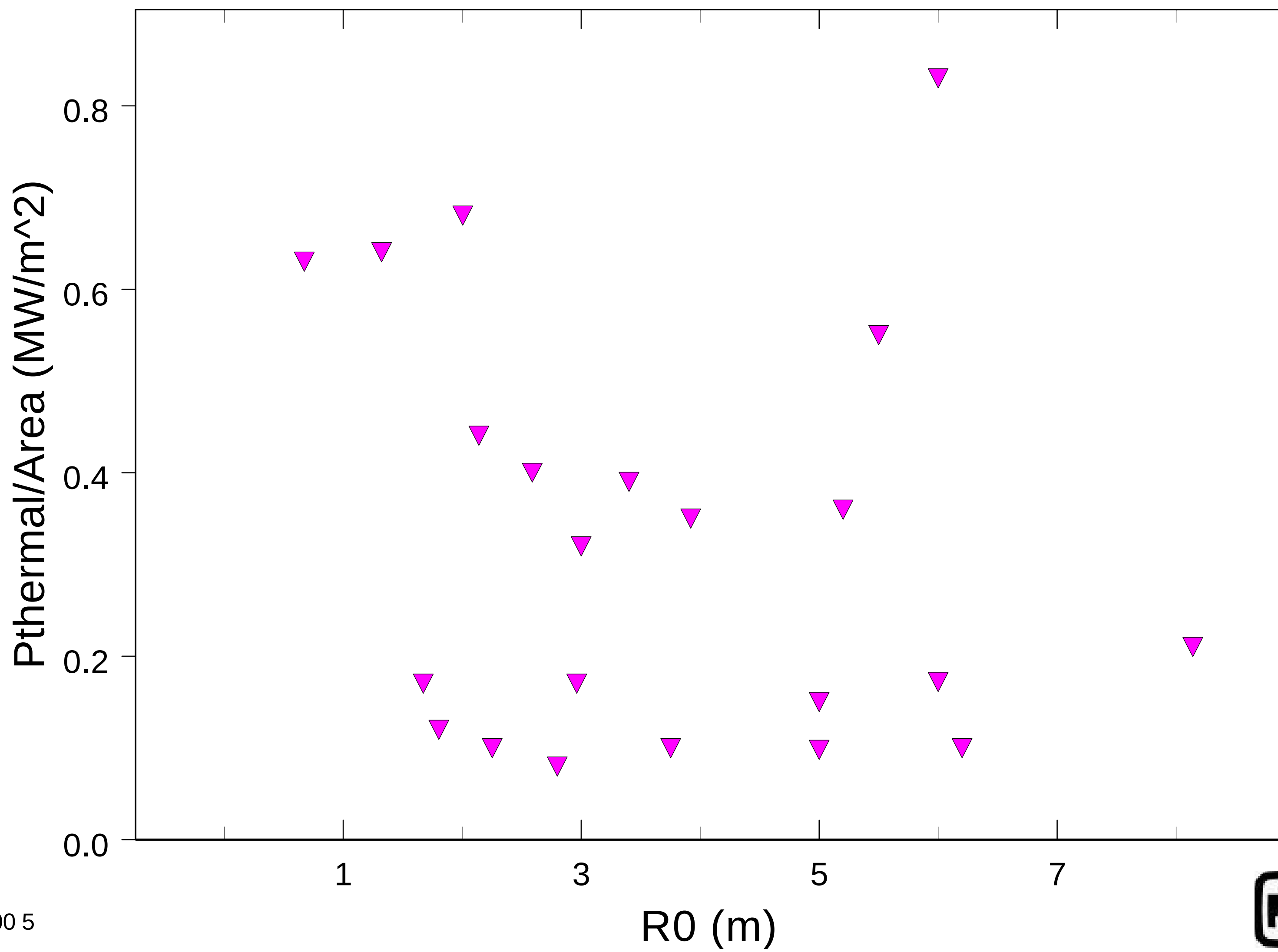
Required Pumping Rate For He + Fuel



Plasma Boundary Power Density



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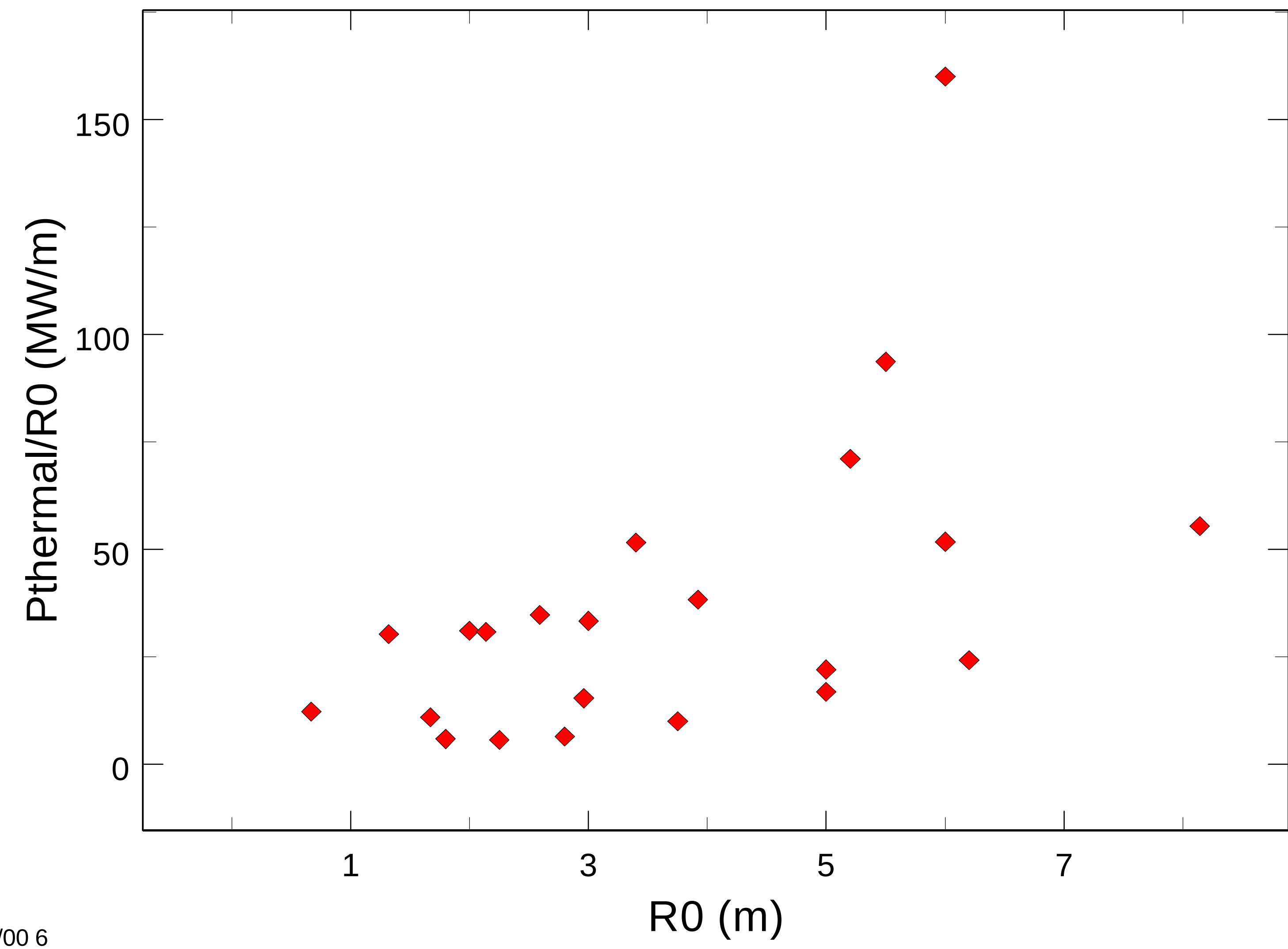
Thermal Power/R0 Ratio



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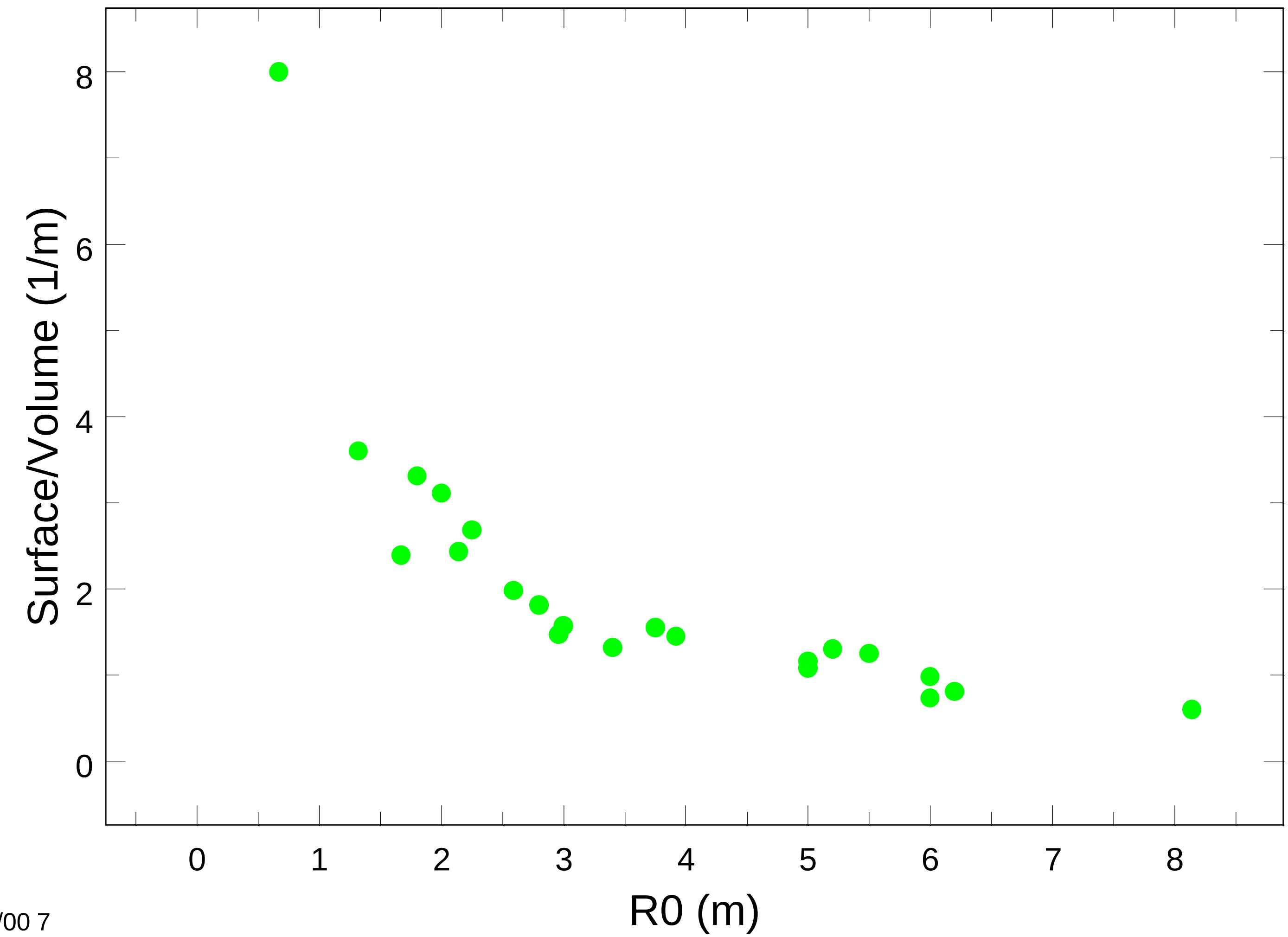
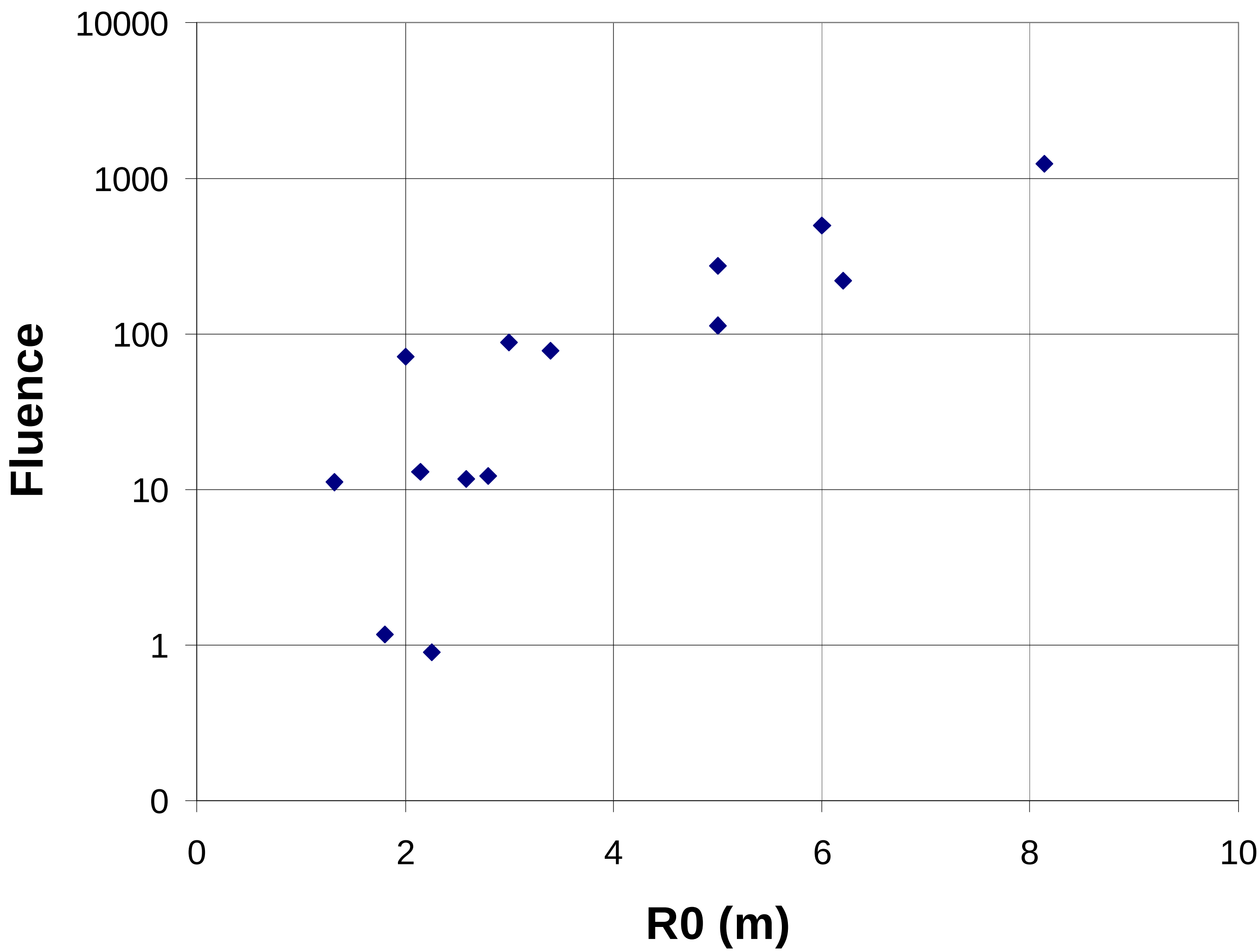
Surface to Volume Ratio



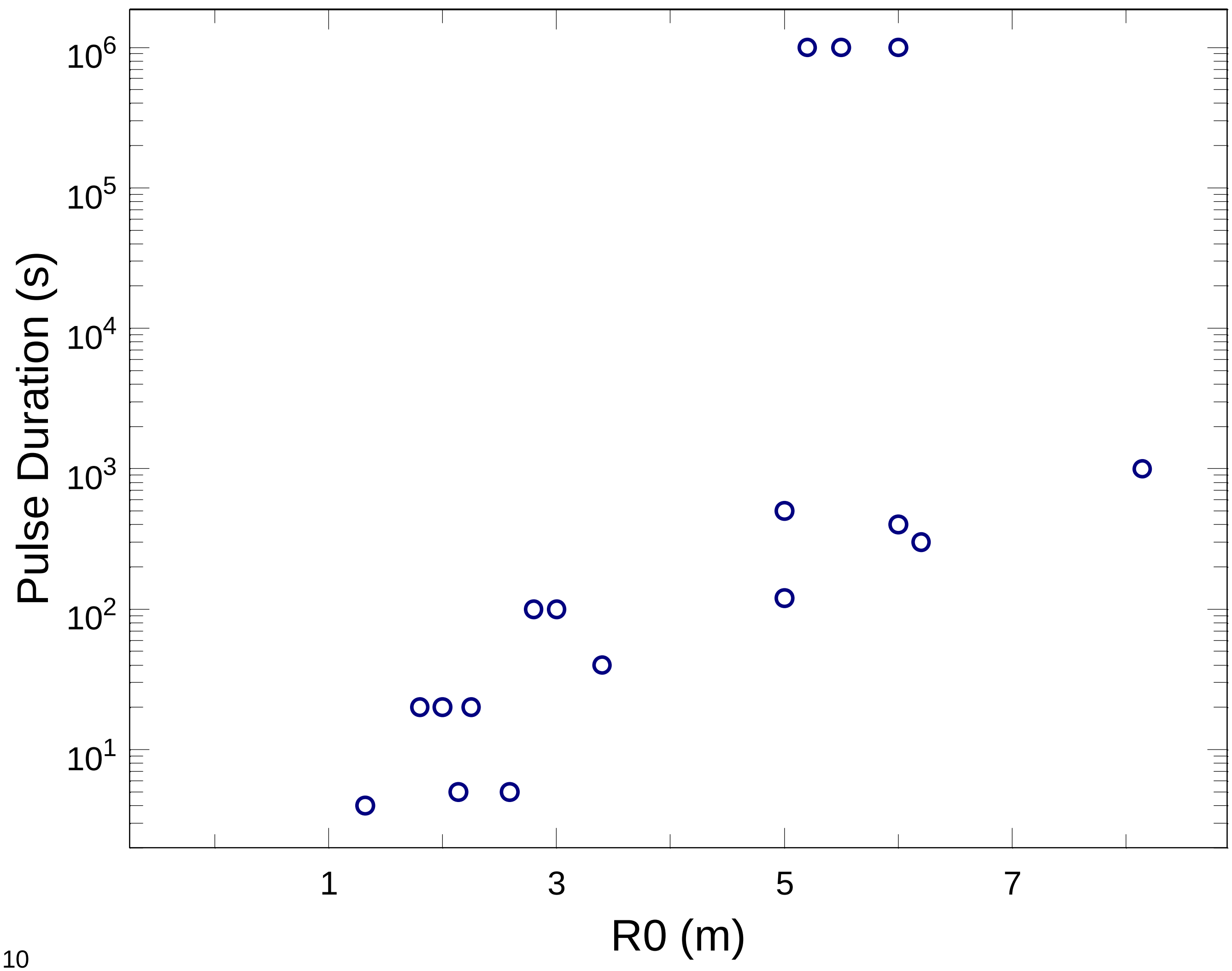
Product of Pulse Length and Wall Load



Pulse Length Issues

- The pulse length requirements needed to explore pressure profile relaxation, alpha particle buildup and burn control are long enough to require active cooling of plasma facing components (PFCs).
- But short duration ELMS and disruptions must also be survived without damage (10-100 MJ/m^2).
- This combination is unique to burning plasma devices.

Burning Plasma Devices Have Long Pulses



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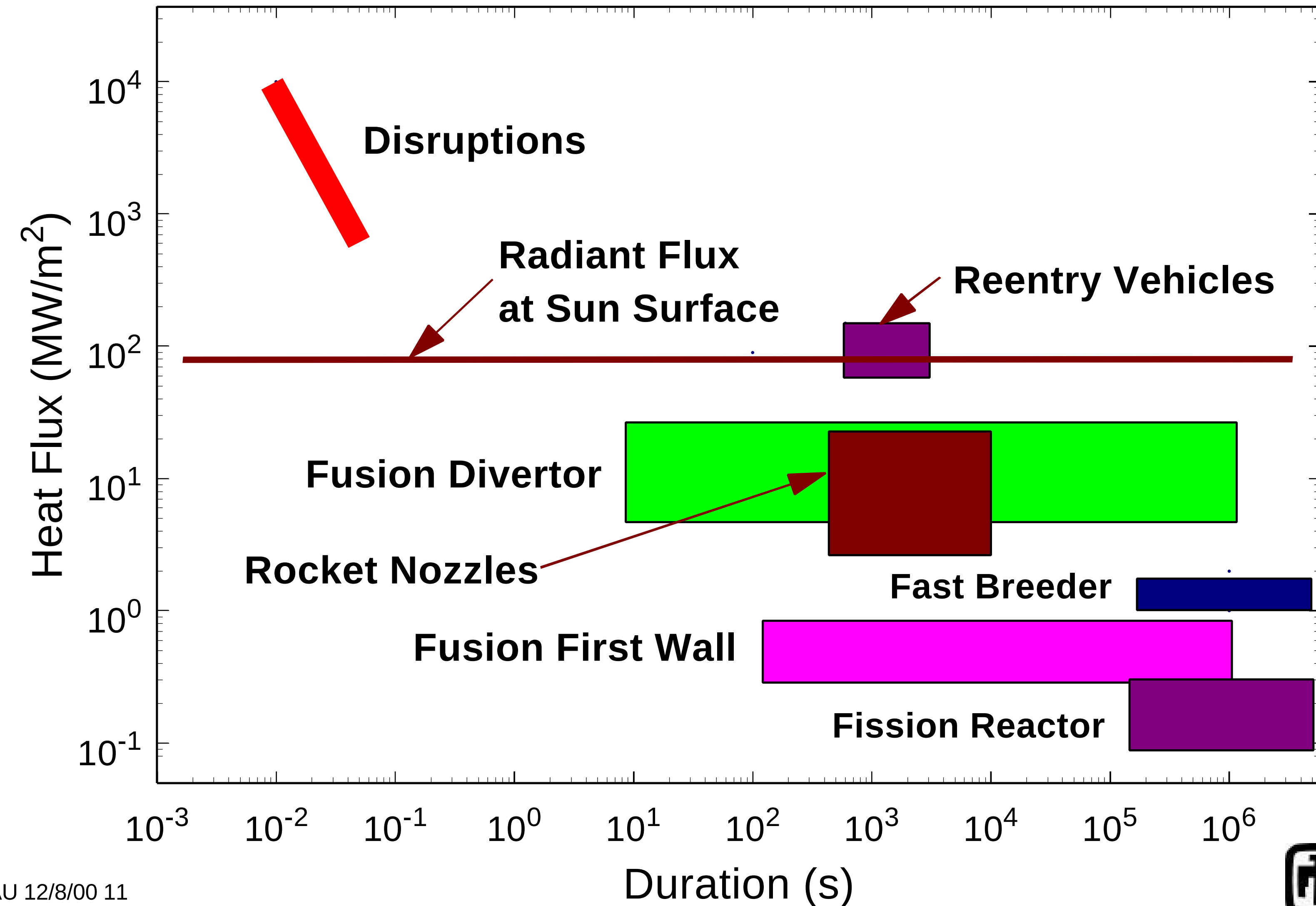
Comparison Relative Heat Fluxes



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PFC Issues

- Actively cooled PFCs have been developed for burning plasma devices
- Erosion lifetimes and fatigue effects have been improved greatly in the past 5 years.
- Materials developments are also promising (better refractory metals)
- Liquid surfaces are being investigated as longer term alternatives that may have higher heat flux capability and long lifetime

PFC Issues

- The lifetime of these actively cooled components is governed by disruption and ELM events.
- There has been significant progress on predicting disruptions and mitigating the effect of disruptions.
  - Neural network prediction of disruptions about 50 ms before they occur with a >90% accuracy
  - Massive gas puffing to mitigate halo currents, energy deposition and current decay rates (liquid jets under development)

PFC Issues

- **Actively cooled PFCs that must withstand disruptions or ELMs, be remotely maintained, and provide for pumping of the correct ratio of DT and helium without contaminating the core plasma cannot be proven on less than a burning plasma device.**

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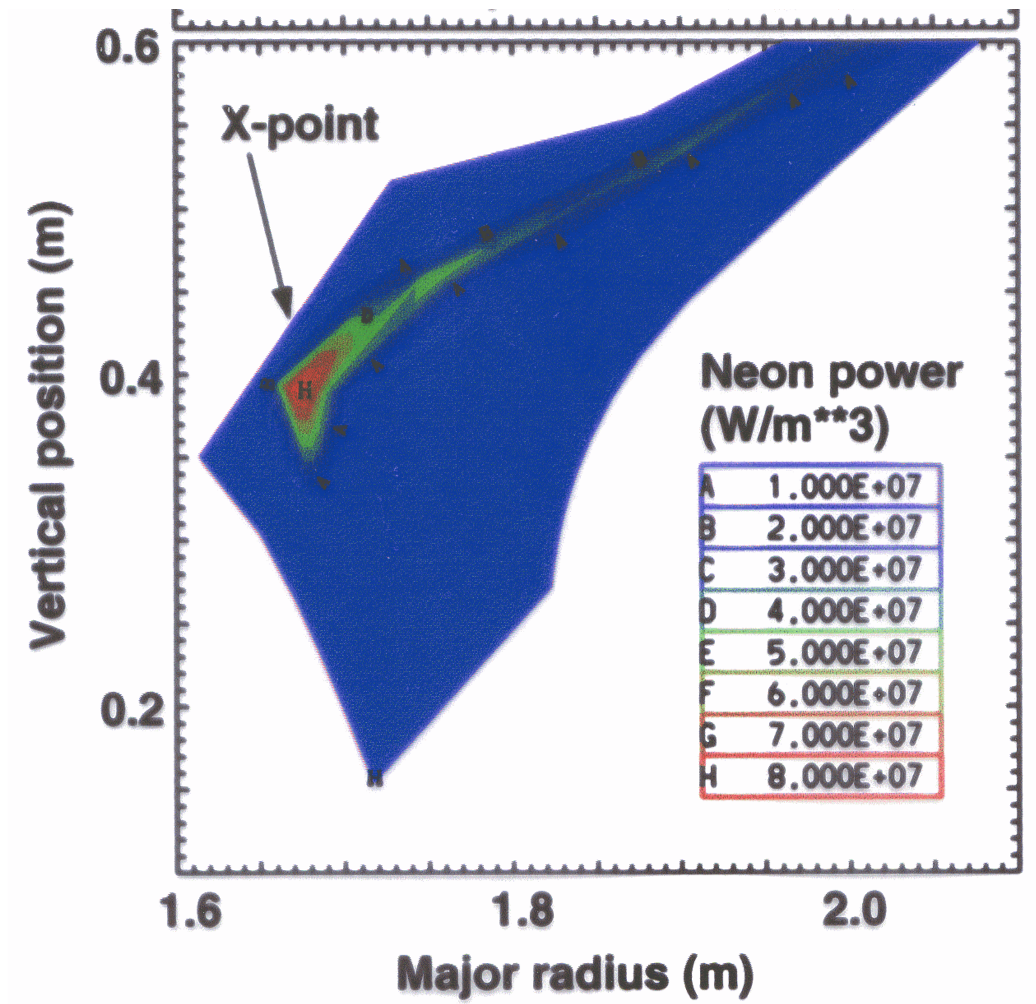
Plasma Core to SOL and Divertor Coupling

- **The divertor needs to be at high density and have some impurities to enter the detached regime where heat loads are reduced.**
- **Complete detachment leads to flow stagnation and may not be compatible with He pumping.**
- **But the SOL needs to have lower density and low neutral pressure for the H-mode pedestal and low wall erosion.**
- **Long pulses and high power also lead to new regimes for plasma wall interactions and erosion.**

Example of Non-Linear Process



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Plasma Core to SOL and Divertor Coupling

- Recent studies with closed pumped divertors on DIII-D have yielded long ELM free high performance discharges with a high T_e edge.
- The optimum solution may be a partially or fully attached divertor plasma if the PFCs can take it.
- The non-linear coupling of the high-power plasma core with the plasma edge and a closed detached divertor cannot be explored except on a burning plasma device.

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Tritium Issues

- The tritium retention and permeation characteristics of most candidate plasma facing materials (PFMs) have been measured.
- But issues of material mixing and redeposition will be unique on a burning plasma device.
- The use of carbon containing materials on a burning plasma device is very questionable because of tritium retention.
- There is very little operating experience with all metal walls in tokamaks.

Materials Science Issues

- Improvements are being made to BCC metals essential to fusion, i.e., copper, steel, tungsten etc.
- This is fundamental materials science research but the potential benefits to fusion are enormous
- Other fields will also benefit from these advances (light bulbs to hypersonic aircraft).
- Liquid surfaces are another area where fundamental science research may benefit fusion devices (especially burning plasma devices)

Conclusions

- **While many of the needed pieces have been developed separately, what is needed is a place to prove that a high performance core can be coupled to a scrape-off layer and to a closed divertor having sufficient density to detach while pumping enough of the helium ash.**
- **A burning plasma experiment will provide the opportunity to perform an integrated test of all these requirements on one device.**