Role of ITER in Fusion Development

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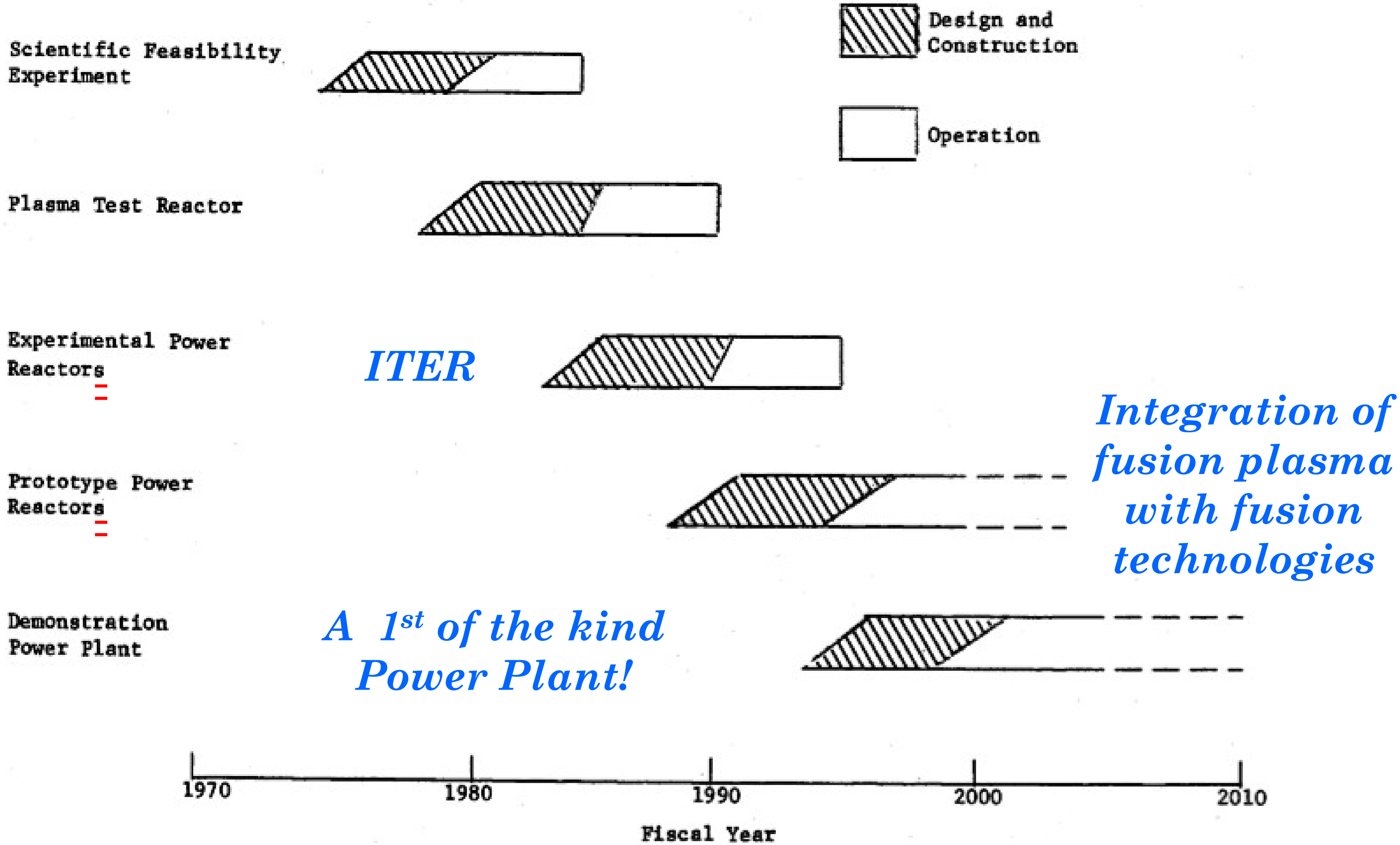
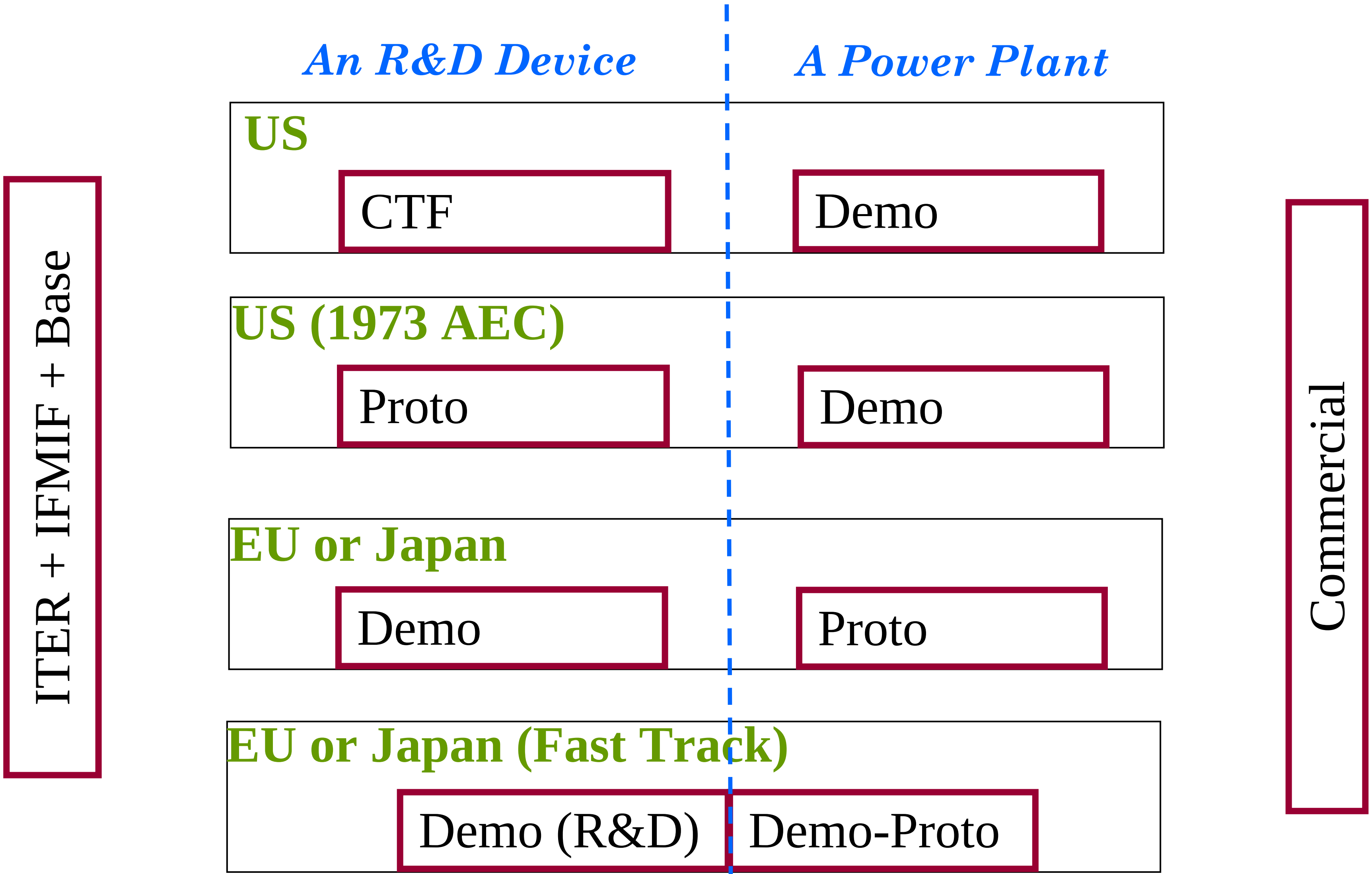
A 35,000 ft view
of fusion development landscape



Projected Fusion-Reactor Development Program
Wash-1267, July 1973

"Fusion Power: Research and Development Requirements." Division of Controlled Thermonuclear Research (AEC).

World-wide Development Scenarios use similar names for devices with different missions!



* Combine Demo (R&D) and Proto in one device

What do we need to bridge the gap between ITER and attractive power plants?

- With ITER construction going forward with US as a partner and increased world-wide interest and effort in developing fusion energy, it will become increasingly important that new major facilities and program in US demonstrate their contributions to developing fusion energy as a key part of their mission.

- Do we have a detailed map for fusion power development?
- How do we optimize such a development path?
  - ✓ What can we do in simulation facilities and what requires new fusion devices?
- How can we utilize existing devices to resolve some of these issues?
  - ✓ Preparation for lunching new facilities.
  - ✓ Resolving issues that can make a difference in any new facilities.

We need to develop a 5,000 ft view

Various devices are proposed in US to fill in the data needed to proceed with a power plant

Many devices are proposed:

- A device that can explore AT burning plasma with high power density and high bootstrap fraction (with performance goals similar to ARIES-RS/AT).
- A device with steady-state operation at moderate Q (even D plasma) to develop operational scenarios (i.e., plasma control), disruption avoidance, divertor physics (and developing fielding divertor hardware), etc.
- Volume Neutron Source for blanket testing.

- Most these devices provide only some of the data needed to move to fusion power. They really geared towards one part of the problem.
- Can we do all these in one device or one facility with minor changes/upgrades and a reasonable cost?
- How can we utilize existing devices to resolve some of these issues?

What is the most cost-effective way to do this?

A holistic optimization approach should drive the development path.

Traditional Approach: Ask each scientific area (i.e., plasma, blanket, …)

- What are the remaining major R&D areas?
- Which of the remaining major R&D areas can be explored in existing devices or simulation facilities (e.g., fission reactors)? What other major facilities are needed?

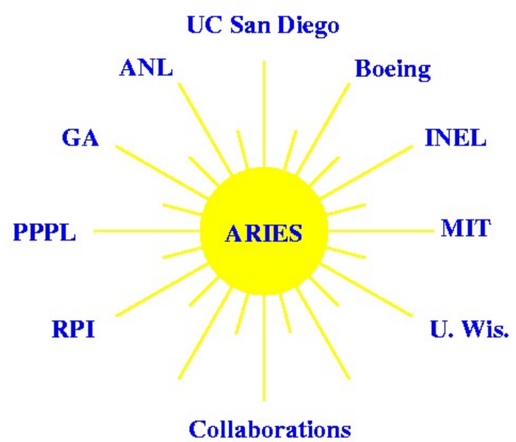
Holistic Approach: Fusion energy development should be guided by the requirements for an attractive fusion energy source

- What are the remaining major R&D areas?
  - ✓ What it the impact of this R&D on the attractiveness of the final product.
- Which of the remaining major R&D areas can be explored in existing devices or simulation facilities (i.e., fission reactors)? What other major facilities are needed?
  - ✓ Should we attempt to replicate power plant conditions in a scaled device or Optimize facility performance relative to scaled objectives

Fusion energy development should be guided by the requirements for a fusion energy source

- No public evacuation plan is required
- Generated waste can be returned to environment or recycled in less than a few hundred years (*i.e.*, not geological time-scales)
- No disturbance of public's day-to-day activities
- No exposure of workers to a higher risk than other power plants
- Closed tritium fuel cycle on site
- Ability to operate at partial load conditions (50% of full power)
- Ability to efficiently maintain power core for accept
- Ability to operate reliably with less than 0.1 major unscheduled shut-down per year

Above requirements must be achieved consistent with a competitive life-cycle cost-of-electricity goal.

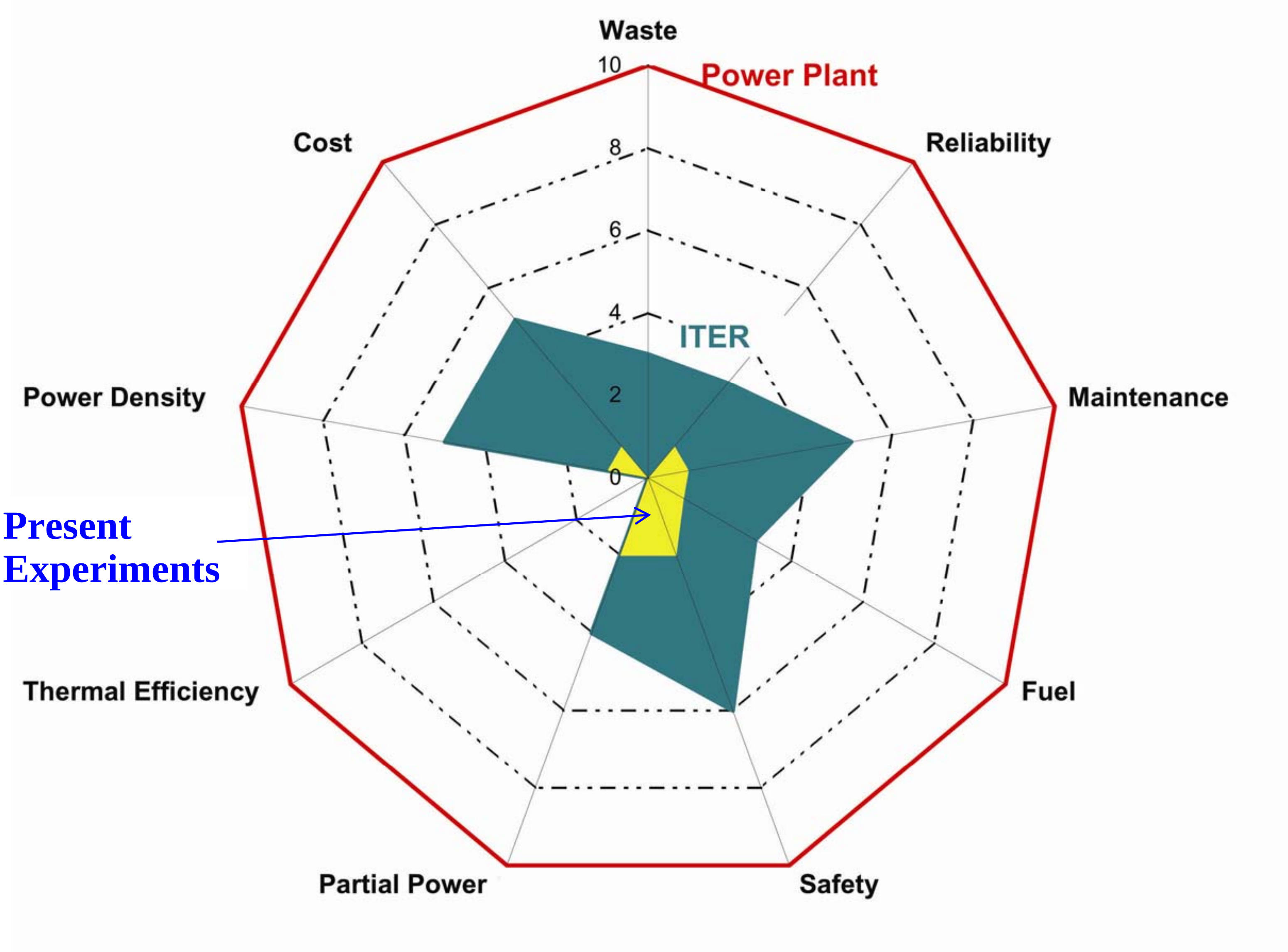


Existing facilities fail to address essential features of a fusion energy source

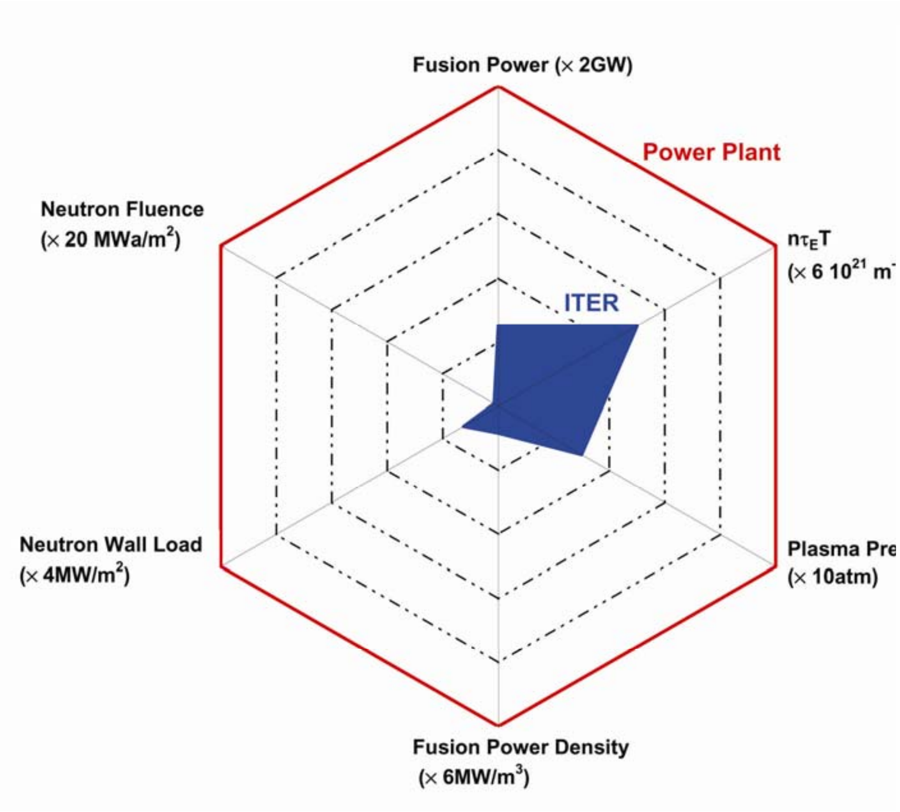
Metric	ITER	
waste	3	need to deal with it, but wrong materials, little fluence
reliability	3	some machine operation, little fluence
maintenance	5	unprototypic construction, modules replaced
fuel	3	tritium handling, but no breeding, no fuel cycle
safety	6	hazards are lower, operations different
partial power	4	experience with operating modes
thermal efficiency	0	no power production, low temperature, wrong materials
power density	5	low average power density, local regions of HHF
cost	5	1st of a kind reactor costs, cost reduction needed

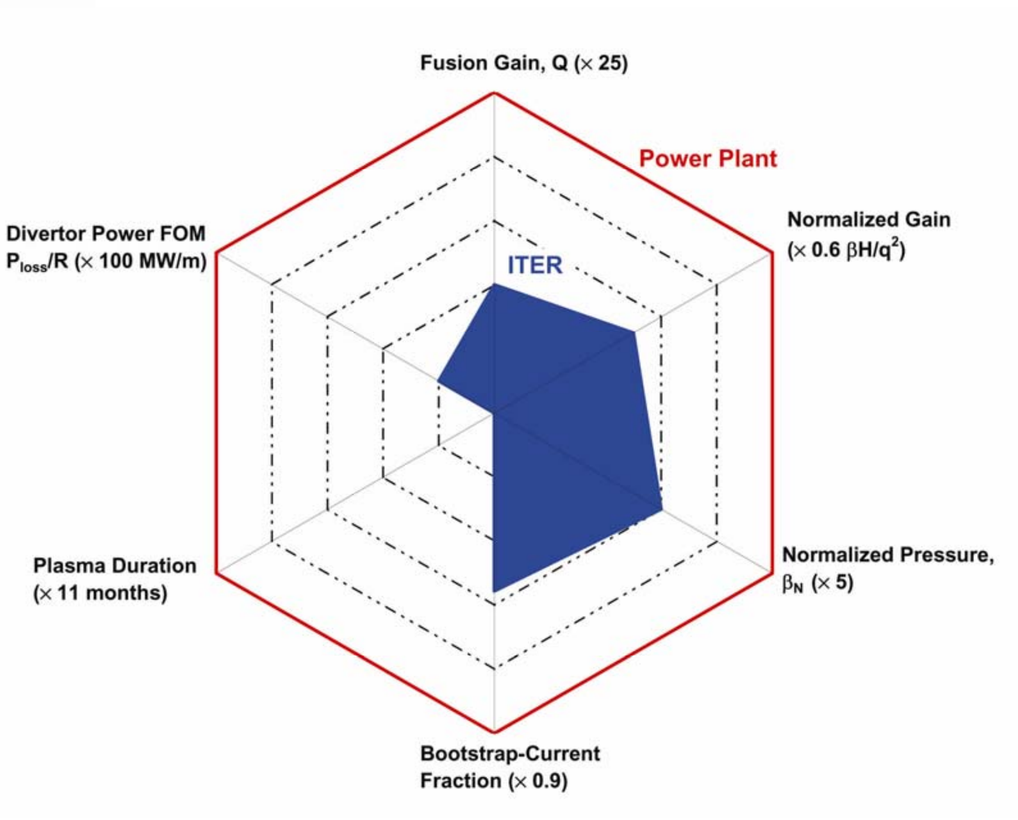
Metric	D3 / JET	
waste	0	little relevance
reliability	1	some machine operation, no fluence
maintenance	1	experience moving tokamak equipment
fuel	1	Some tritium handling, no breeding, no fuel cycle
safety	2	hazards much lower, operations much different
partial power	2	experience with operating modes
thermal efficiency	0	no power conversion
power density	1	low power handling required, some divertor heating
cost	1	not relevant to a power plant

ITER is a major step forward but there is a long road ahead.



Power plant features and not individual parameters should drive the development path





- Absolute parameters

- Dimensionless parameters

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ARIES studies emphasize holistic R&D needs and their design implications

Traditional approach	Concurrent engineering/physics
Plasma	Power control
Blankets	Power and particle management
Divertors	Fuel management
Magnets	Maintenance
Vacuum vessel	Safety
	Waste
	Cost

- This approach has many benefits (see below)

Examples of holistic issues for Fusion Power

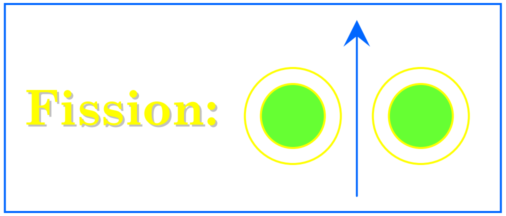
- Power & Particle management: Demonstrate extraction of power core high-grade heat, divertor power and particle handling, nuclear performance of ancillary equipment.

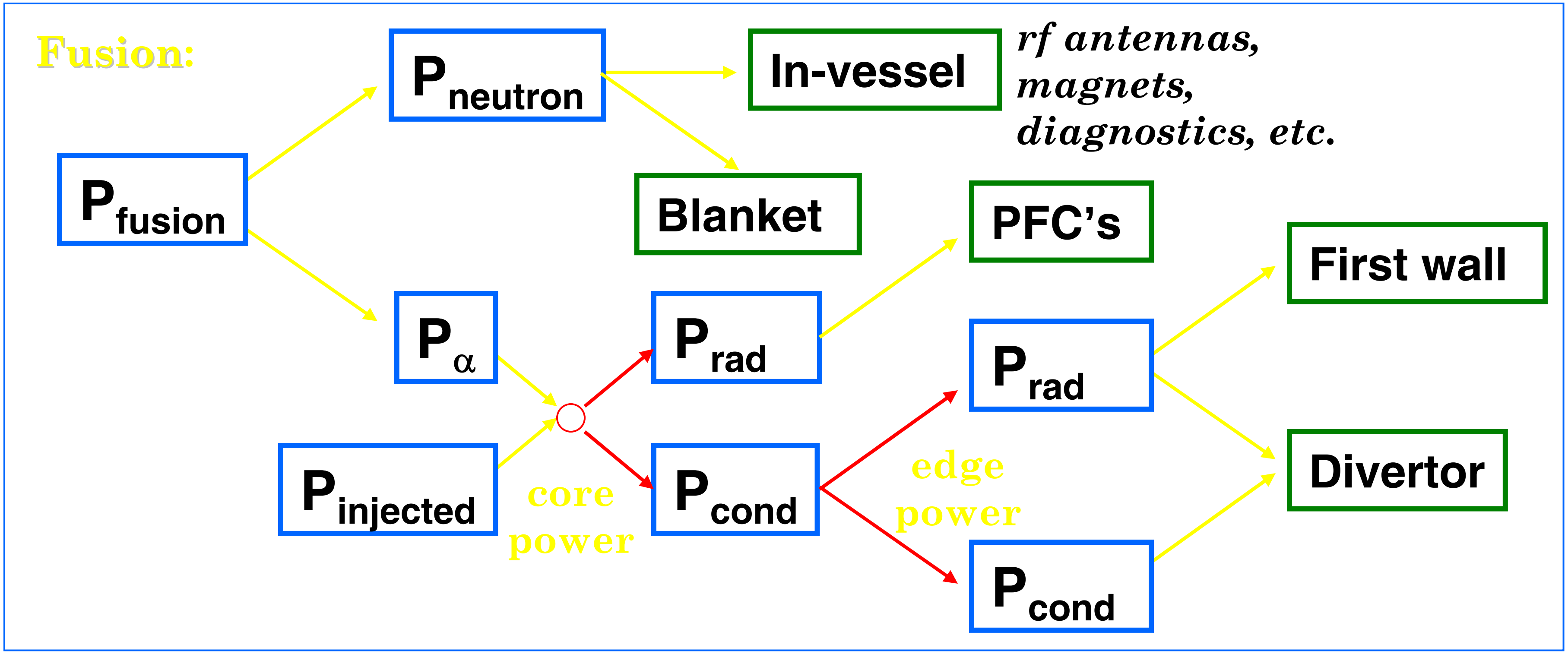
- Fuel management: Demonstrate "birth to death" tritium management in a closed loop with self-sufficient breeding and full accountability of tritium inventory.

- Safety: Demonstrate public and worker safety of the integral facility, capturing system to system interactions.

- Plant operations: Establish the operability of a fusion energy facility, including plasma control, reliability of components, inspectability and maintainability of a power plant relevant tokamak.

<u>Power & particle management</u>: Demonstrate extraction of power core high-grade heat, divertor power and particle handling, nuclear performance of ancillary equipment.

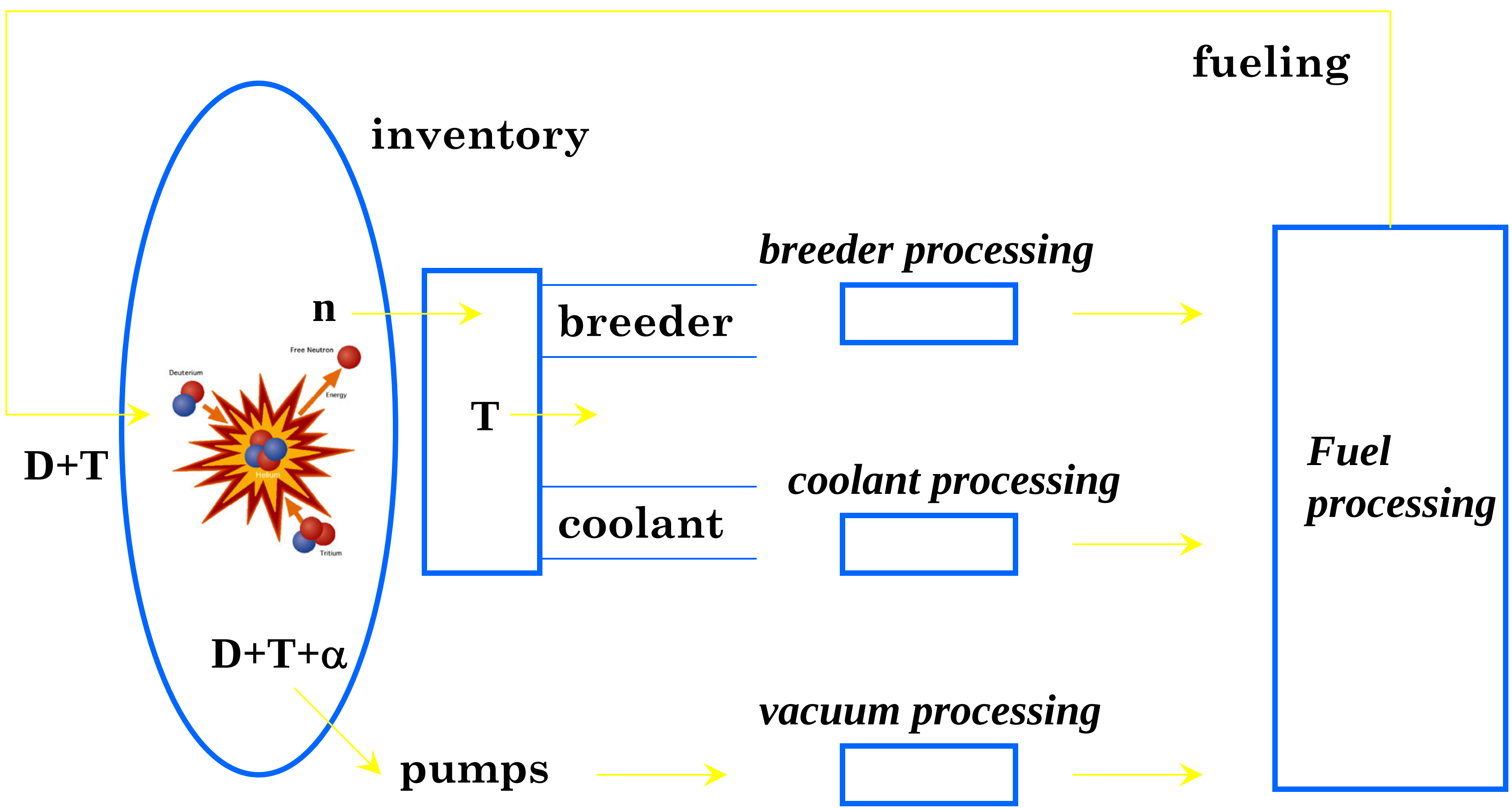




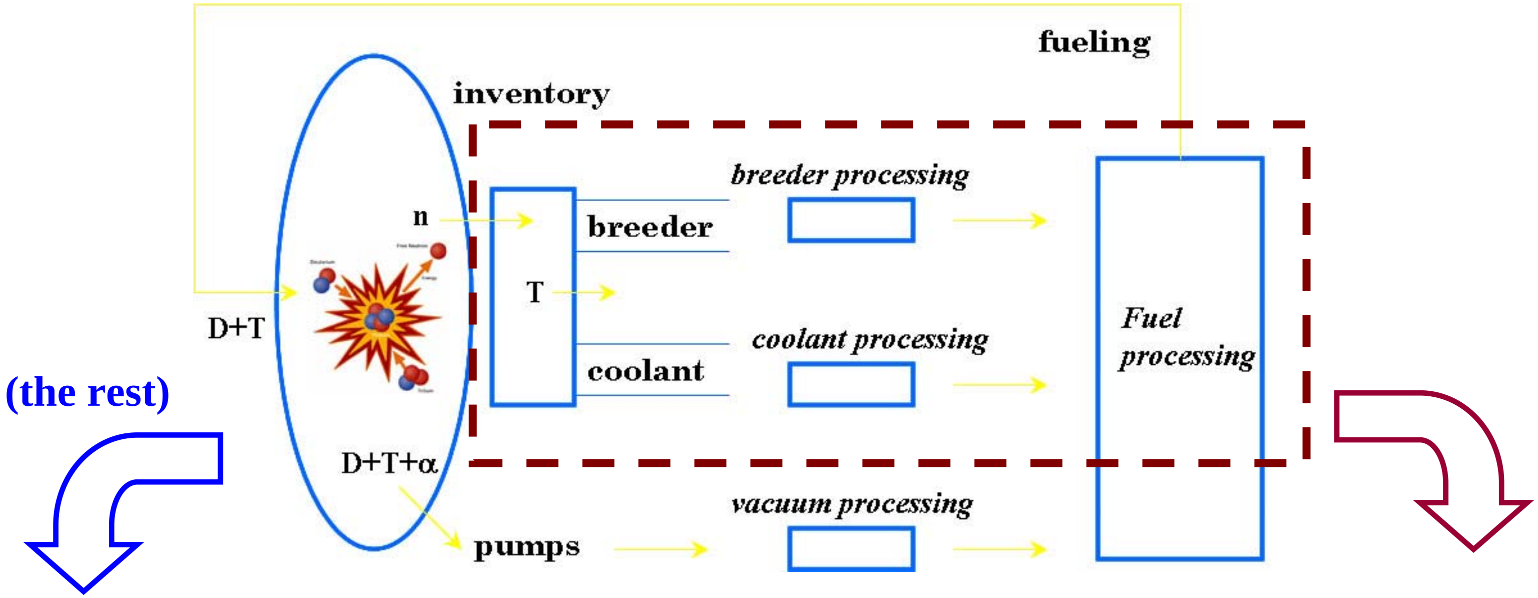
A holistic approach to Power and Particle Management

- Does not allow problem cannot be solved by transferring to another system:
  - ✓ A 100% radiating plasma transfers the problem from divertor to the first wall.
- Allows Prioritization of R&D:
  - ✓ Systems code can be used to find power plant cost (or any other metric) as a function of divertor power handling. This leads to a "benefit" metric that can be compared to other R&D areas, for example increasing plasma β. We can then answer: should we focus on power flow or improving plasma β.
- Solution may come from other areas:
  - ✓ Low recirculating power
  - ✓ A higher blanket thermal efficiency reducing input fusion power
- This area may have a profound impact on next-step facilities.

Fuel management: Demonstrate "birth to death" tritium management in a closed loop with self-sufficient breeding and full accountability of tritium inventory.



Fuel Management divides naturally along physical boundaries



- ITER provides most of the required data.
- Issues include minimizing T inventory and T accountability

- Can & should be done in a fission facility.
- Demonstrate in-situ control of breeding rate (too much breeding is bad).
- Demonstrate T can be extracted from breeder in a timely manner (minimum inventory).

There is a need to examine fusion development scenarios in detail

- Any next-step device should advance power plant features on the path to a commercial end product.
- We need to start planning for facilities and R&D needed between ITER and a power plant.
- Metrics will be needed for cost/benefit/risk tradeoffs
- An integrated, "holistic" approach provides a path to an optimized development scenario and R&D prioritization.
- We should consider the needs of next-step facilities in the R&D in current facilities as well as initiating R&D needed to ensure maximum utilization of those facilities.