

ARIES “Pathways” Program

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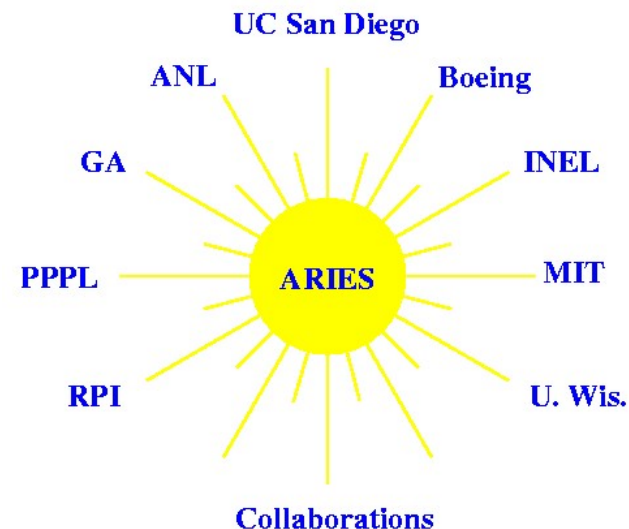
ARIES brainstorming meeting

UC San Diego

April 3-4, 2007

Electronic copy: <http://aries.ucsd.edu/najmabadi/>

ARIES Web Site: <http://aries.ucsd.edu/ARIES>



Mission of the ARIES Pathways Program

Mission Statement:

- The ARIES Pathways program will investigate what the fusion program needs to do, in addition to successful operation of ITER, in order to transform fusion into a commercial reality.
- The US fusion energy program anticipates a demonstration power plant, DEMO, which will be the link between government-sponsored and industry-sponsored development of fusion. DEMO is probably built by the private industry under partnership or “subsidy” from the government (from FESAC Development path panel).
- The pathways program will investigate what is needed, in addition to successful operation of ITER, to be ready for DEMO.

**How to we get from ITER to an
attractive final product**

Scientific Feasibility
Experiment



 Design and
Construction

 Operation

Plasma Test Reactor



Experimental Power
Reactors

ITER



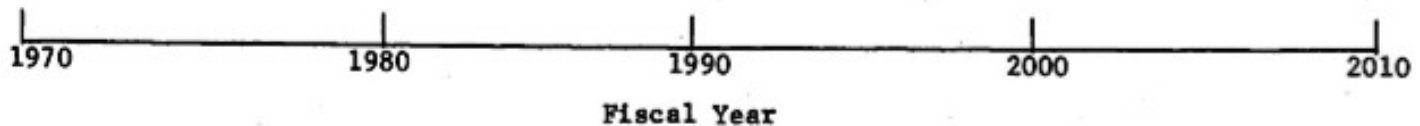
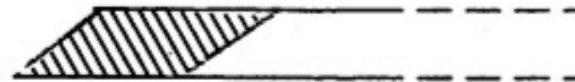
Prototype Power
Reactors



*Integration of
fusion plasma
with fusion
technologies*

Demonstration
Power Plant

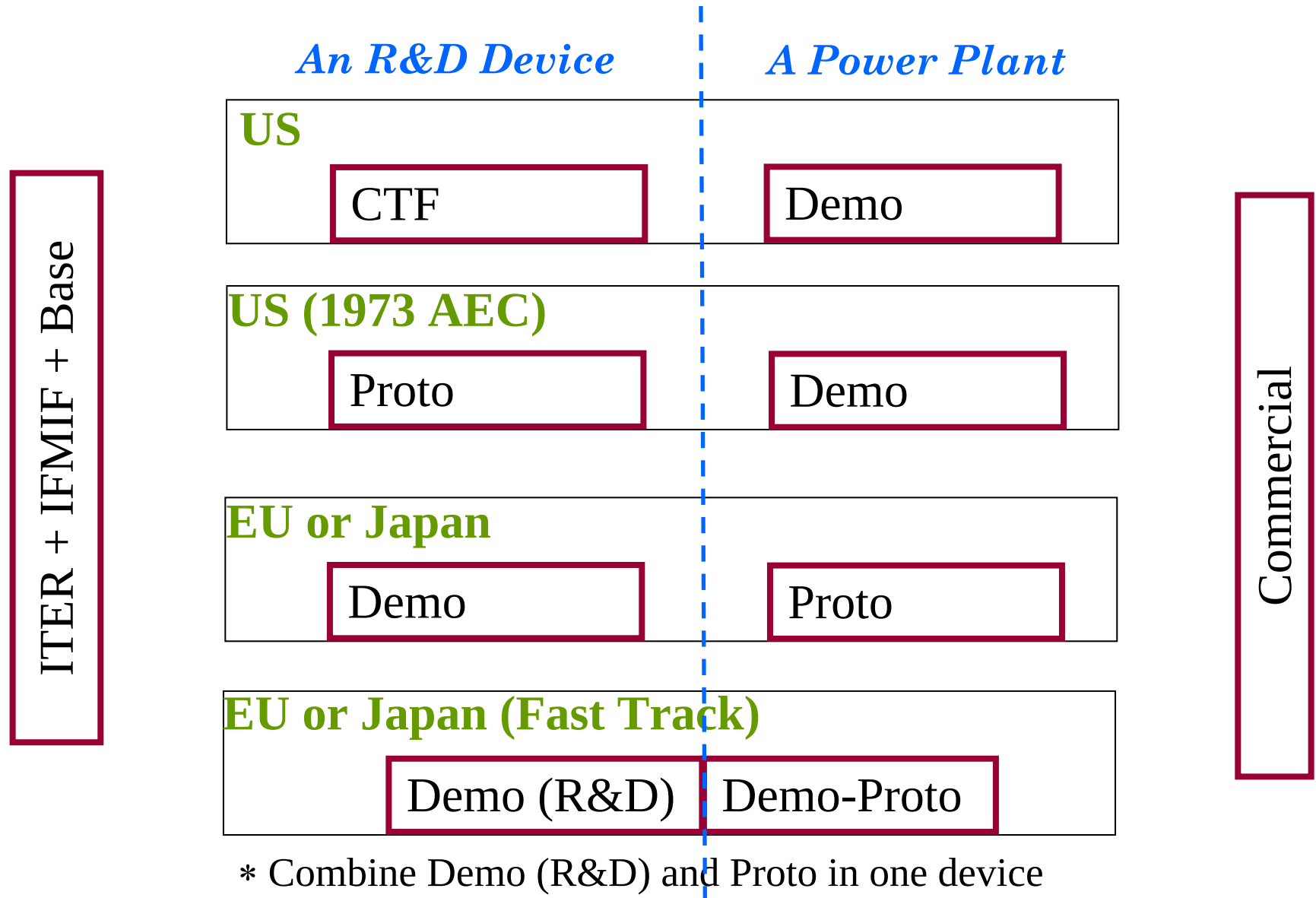
*A 1st of the kind
Power Plant!*



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!



**In the ITER area,
we need to develop
a 5,000 ft view**

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.
- We need a detailed map for fusion power development!
- How do we optimize such a development path?
 - ✓ What are the remaining R&D issues?
 - ✓ What are the metrics for distributing resources among R&D issues?
 - ✓ What can we do in simulation facilities and what requires new fusion devices?
 - ✓ How can we utilize existing devices to help us Prepare for lunching new facilities (resolving issues that can make a difference in any new facilities).

**What are the remaining R&D
issues?**

An Integrated “holistic” optimization approach should drive the development path.

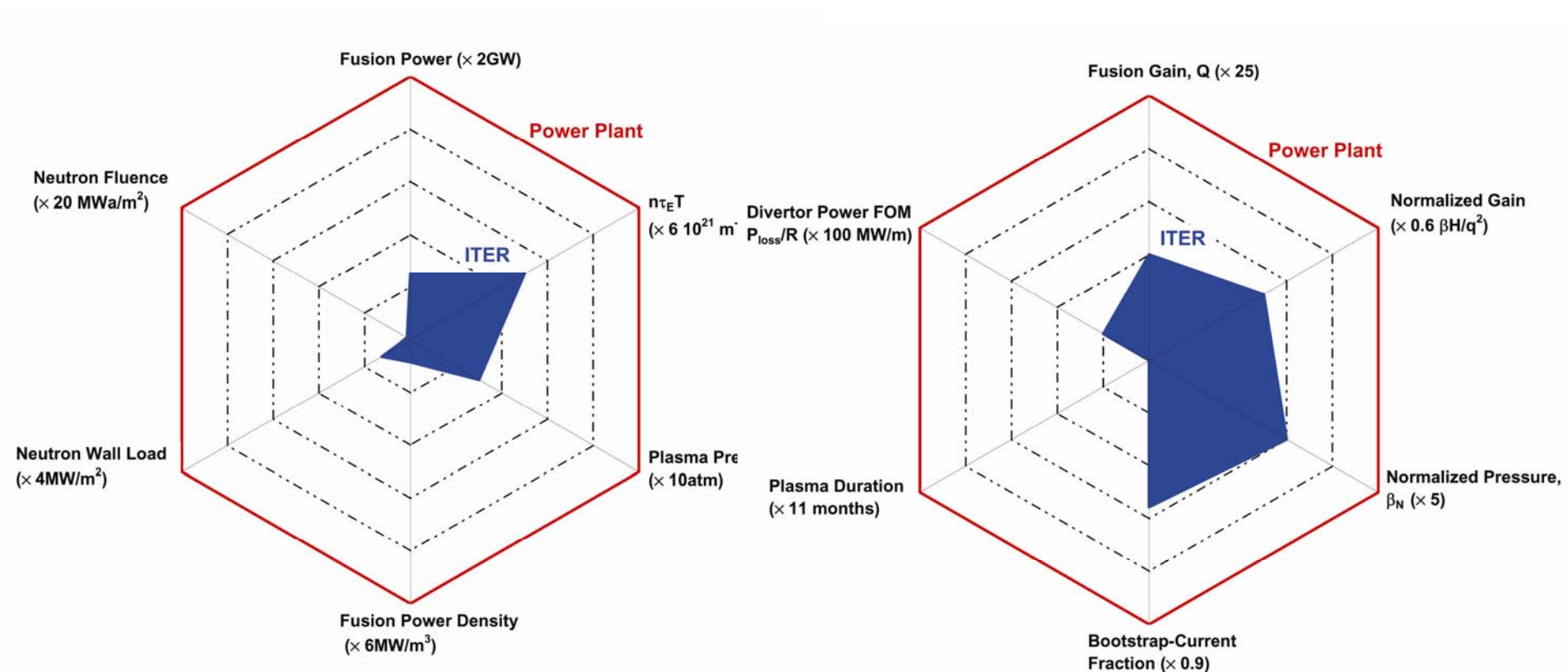
Traditional Approach: Ask each scientific area (i.e., plasma, blanket, ...)

- What are the remaining major R&D areas?
 - ✓ We have generated many “to do” lists.
 - ✓ There are little prioritization of R&D.
- 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?

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.

Comparison of Predicted ITER performance versus a fusion power plant (ARIES-RS/AT)



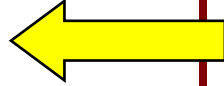
➤ Absolute parameters

➤ Dimensionless parameters

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

An Integrated “holistic” optimization approach should drive the development path.

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?
 - ✓ Are we generating all of the information needed by the industry to move forward? (Data needed to convince power industry to move forward and licensing authorities to license the device, ...).
- What is the impact of this R&D on the attractiveness of the final product? (What are the metrics for distributing resources among R&D issues?)
- 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

Elements of the Case for Fusion Power Were Developed through Interaction with Representatives of U.S. Electric Utilities and Energy Industry

- **Have an economically competitive life-cycle cost of electricity**
- **Gain Public acceptance by having excellent safety and environmental characteristics**
 - ✓ No disturbance of public's day-to-day activities
 - ✓ No local or global atmospheric impact
 - ✓ No need for evacuation plan
 - ✓ No high-level waste
 - ✓ Ease of licensing
- **Reliable, available, and stable as an electrical power source**
 - ✓ Have operational reliability and high availability
 - ✓ Closed, on-site fuel cycle
 - ✓ High fuel availability
 - ✓ Capable of partial load operation
 - ✓ Available in a range of unit sizes

Low-activation material

Fusion physics & technology

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

Metric

ITER

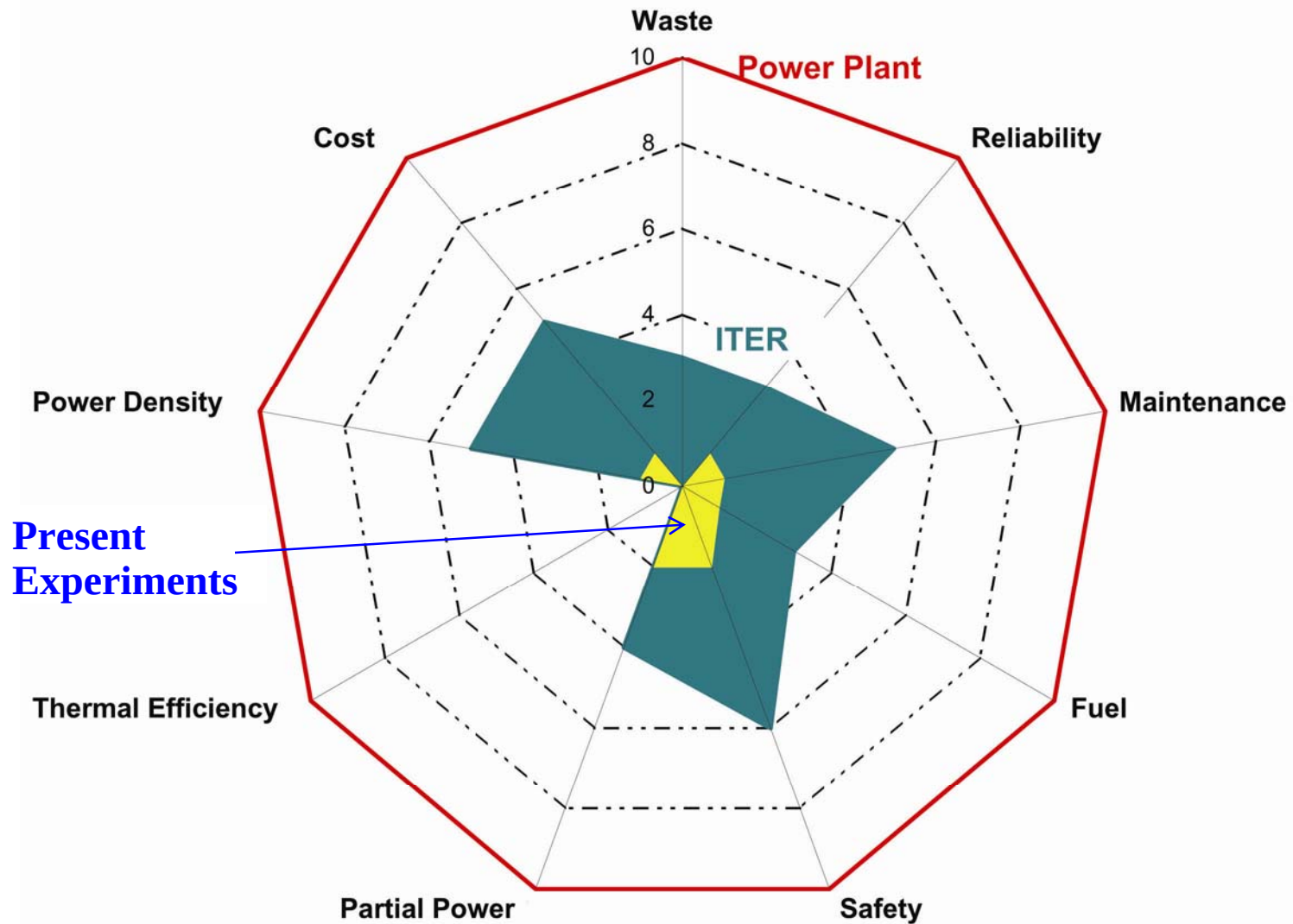
waste		3	need to deal with it, but wrong materials, little fluence
reliability		3	some machine operation, little fluence
maintenance		5	unprototypic construction, modules replaced
fuel		3	tritium handling, but no breeding, no fuel cycle
safety		6	hazards are lower, operations different
partial power		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

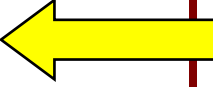
waste		0	little relevance
reliability		1	some machine operation, no fluence
maintenance		1	experience moving tokamak equipment
fuel		1	Some tritium handling, no breeding, no fuel cycle
safety		2	hazards much lower, operations much different
partial power		2	experience with operating modes
thermal efficiency		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.



An Integrated “holistic” optimization approach should drive the development path.

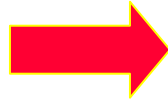
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ARIES studies emphasize holistic R&D needs and their design implications

Traditional approach

Plasma
Blankets
Divertors
Magnets
Vacuum vessel



Concurrent engineering/physics

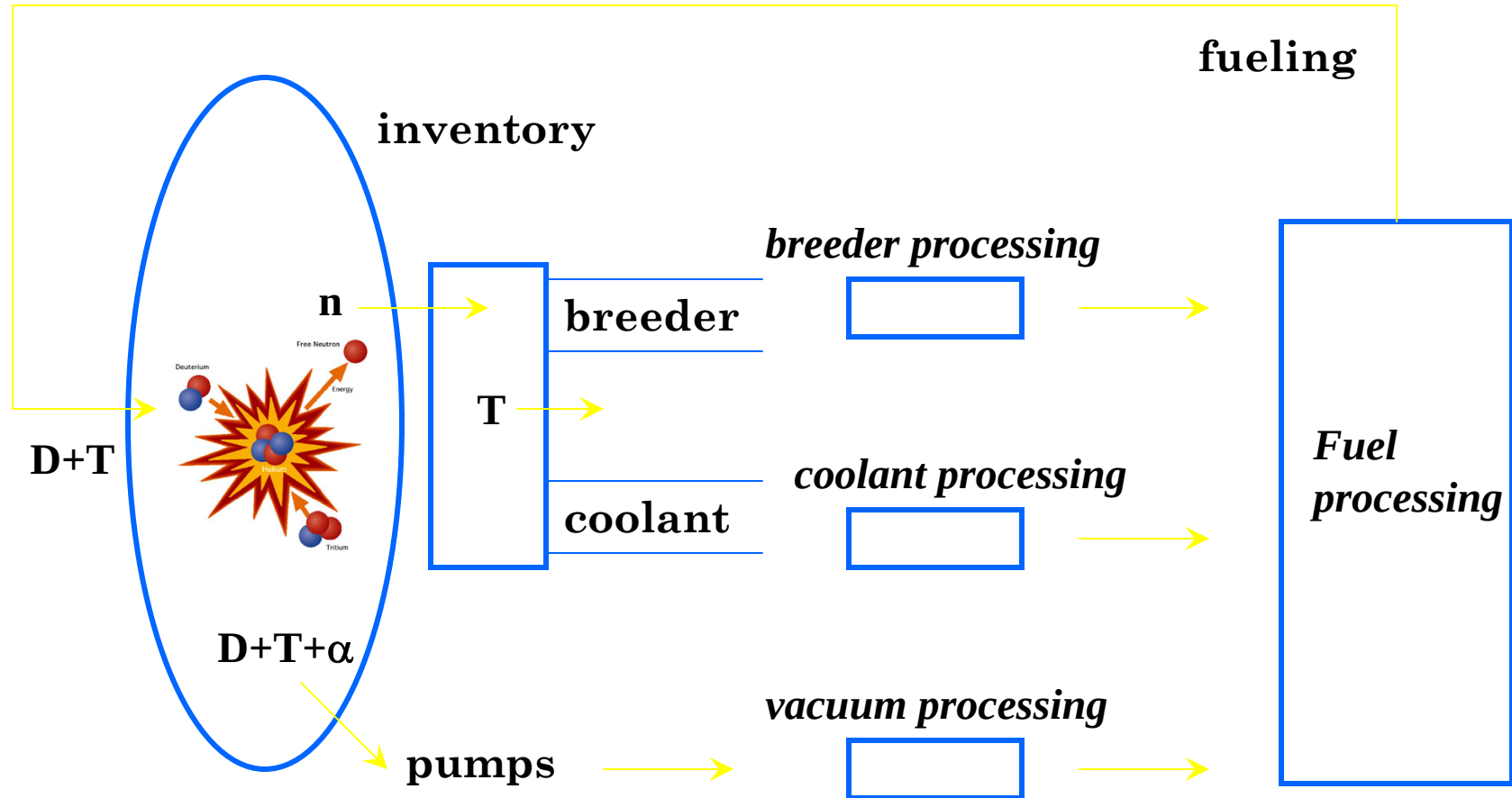
Power control
Power and particle management
Fuel management
Maintenance
Safety
Waste
Cost

➤ This approach has many benefits (see below)

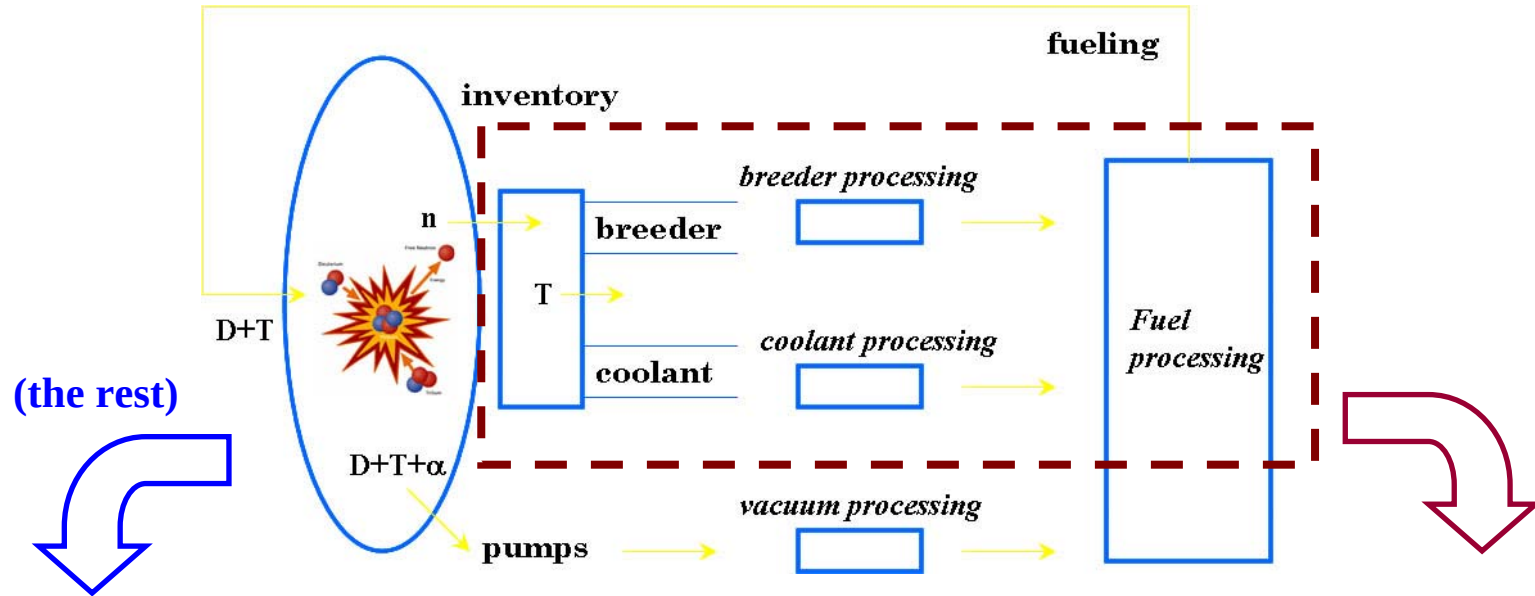
Examples of holistic issues for Fusion Power

- 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.

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



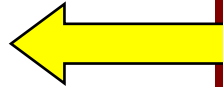
- ITER provides most of the required data.
- Issues include minimizing T inventory and T accountability

- Most of R&D can 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).

ARIES Pathways Approach

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

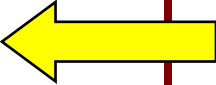
- What are the remaining major R&D areas?
 - ✓ Are we generating all of the information needed by the industry to move forward? (Data needed to convince power industry to move forward and licensing authorities to license the device, ...).



- Form an industrial advisory committee to help define (or refine) requirements for an attractive fusion energy source, for the demo, and helps guide in generating all of the information needed by the industry to move forward? (Data needed to convince power industry to move forward and licensing authorities to license the device, ...).
- Organize ourselves among concurrent physics/engineering issues, review previous work, and define remaining R&D areas.

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Do ARIES Designs Provide sufficient information to develop these metrics?

- ARIES designs were point designs, meant to provide “long-term” guidance to the program.
- We never worked on one particular design long enough to understand and document all trade-offs.
- Prioritization of R&D requires a quantitative measure: Trade-off studies around several design points.

- Revisit ARIES tokamak designs, and investigate the parameter space and impact of various constraints.
Examples:
 - Is it better to push on for a higher β or divertor heat flux?
 - It is better to push on for a higher β or high-efficiency blanket?

Timeline for the ARIES Pathways program

- First year:
 - Focus on defining R&D issues and system studies to identify high-leverage areas.
- Second and third years:
 - Develop embodiments for a next-step device (CTF).