Role of ITER in Fusion Development

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A 35,000 ft view of fusion development landscape
Integration of fusion plasma with fusion technologies

ITER

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!

- **US**
  - **CTF**
  - **Demo**

- **US (1973 AEC)**
  - **Proto**
  - **Demo**

- **EU or Japan**
  - **Demo**
  - **Proto**

- **EU or Japan (Fast Track)**
  - **Demo (R&D)**
  - **Demo-Proto**

* 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 is 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 acceptable operability
- 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** | **D3/JET**
--- | --- | ---
waste | 3 need to deal with it, but wrong materials, little fluence | 0 little relevance
reliability | 3 some machine operation, little fluence | 1 some machine operation, no fluence
maintenance | 5 unprototypic construction, modules replaced | 1 experience moving tokamak equipment
fuel | 3 tritium handling, but no breeding, no fuel cycle | 1 Some tritium handling, no breeding, no fuel cycle
safety | 6 hazards are lower, operations different | 2 hazards much lower, operations much different
partial power | 4 experience with operating modes | 2 experience with operating modes
thermal efficiency | 0 no power production, low temperature, wrong materials | 0 no power conversion
power density | 5 low average power density, local regions of HHF | 1 low power handling required, some divertor heating
cost | 5 1st of a kind reactor costs, cost reduction needed | 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
A holistic optimization approach should drive the development path.

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

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

<table>
<thead>
<tr>
<th>Traditional approach</th>
<th>Concurrent engineering/physics</th>
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<tr>
<td>Plasma</td>
<td>Power control</td>
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<td>Blankets</td>
<td>Power and particle management</td>
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<td>Divertors</td>
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<td>Vacuum vessel</td>
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- 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.
Power & particle management: Demonstrate extraction of power core high-grade heat, divertor power and particle handling, nuclear performance of ancillary equipment.

**Fusion:**

- $P_{\text{fusion}}$
- $P_{\alpha}$
- $P_{\text{injected}}$
- $P_{\text{cond}}$
- $P_{\text{rad}}$

**In-vessel**

- rf antennas, magnets, diagnostics, etc.

**Fission:**

- $P_{\text{neutron}}$

**Blanket**

**PFC’s**

**First wall**

**Divertor**
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 $\beta$. We can then answer: should we focus on power flow or improving plasma $\beta$.

- 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.