the Case for ITER

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ITER

INTERNATIONAL PROJECT
Engineering Design Phase (1992 – 2001)
Japan
European Union
Russian Federation
(US until 1999)
negotiations among partners:
above + Canada

<table>
<thead>
<tr>
<th></th>
<th>ITER</th>
</tr>
</thead>
<tbody>
<tr>
<td>major radius</td>
<td>6.2 m</td>
</tr>
<tr>
<td>minor radius</td>
<td>2.0 m</td>
</tr>
<tr>
<td>plasma current</td>
<td>15 MA</td>
</tr>
<tr>
<td>toroidal field</td>
<td>5.3 T</td>
</tr>
<tr>
<td>(\kappa/\delta)</td>
<td>1.85/0.49</td>
</tr>
<tr>
<td>fusion power amplification</td>
<td>(\geq 10)</td>
</tr>
<tr>
<td>fusion power</td>
<td>400 MW (800 MW)</td>
</tr>
<tr>
<td>burn duration</td>
<td>400 s (3000 s)</td>
</tr>
<tr>
<td>external heating power</td>
<td>73 MW (110 MW)</td>
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</tbody>
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construction costs (including deferred items & management costs):
4.57 b€ (EU costing)
partner’s contributions in kind
role of ITER in Europe’s vision

• burning plasma physics
• integration of technology with physics
• demonstrate and test fusion power plant technologies

ITER Design Goals

Physics:
• ITER is designed to produce a plasma dominated by $\alpha$-particle heating
• produce a significant fusion power amplification factor ($Q = 10$) in long-pulse operation
• aim to achieve steady-state operation of a tokamak ($Q = 5$)
• retain the possibility of exploring ‘controlled ignition’ ($Q = 30$)

Technology:
• demonstrate integrated operation of technologies for a fusion power plant
• test components required for a fusion power plant
• test concepts for a tritium breeding module
role of ITER in Europe’s vision

- ITER is the fastest path of a success-oriented strategy to a reactor
- patience with fusion as an energy option is running short

**the King Panel (including leading industrialists) report:**
The ITER project is the essential step towards energy production on a fast track.

**Economist July 18, 2002:**
- fusion has demonstrated a new physics constant: the 30 years to fusion power
- "the only reason to understand burning plasmas is in order to build a commercial fusion power-plant"
tokamak research is mature for the step to a burning plasma - (1)

ITER incorporates all successful developments:
- elongated (D-shaped) cross-section
- divertor
- superconducting coils
- DT operation
tokamak research is mature for the step to a burning plasma - (2) the progress in performance measure $n T \tau$

steady, rapid progress of tokamak performance
natural next step: burning plasma

$n$... plasma density
$T$... plasma temperature
$\tau$... energy confinement time (a measure of the quality of the thermal insulation)
tokamak research is mature for the step to a burning plasma - (3) targeted research to resolve remaining issues

confinement at high $n/n_{Gr}$
ITER’s capabilities as a burning plasma experiment

ITER has also other missions besides burning plasma physics:

• but all its mission goals require it to carry out foremost an extensive and ambitious physics programme

• its essential design features give it the capability to do this
  - pulse length (3000 s) and duty cycle (20%)
  - diagnostic access & facilities
  - flexible heating, current drive system
    • total power
    • composition
  - divertor exchange capability

even for a partner who values differently the mission objectives of ITER it gives best value/cost \([\text{burn-seconds}/\$] \)

*) or \( (\tau_{\text{burn}}/\tau_E)/\text{cost} \) or \( (\tau_{\text{burn}}/\tau_{\text{skin}})/\text{cost} \) or .....
• advanced scenarios:
  • sample scenarios illustrative
  • will be a primary research objective
    (in particular regarding $\alpha$-particle physics)
• sample calculations:
  • “weak central shear”
  • $I_p=9$MA, $q_{95}=5.3$
  • $H_{98(y,2)}=1.6$, $\beta_N=2.95$
  • $f_{bs}=48\%$, $f_{CD}=52\%$
  • $P_{RF}+P_{NB}=29+30$MW, $P_{fus}=356$MW

ITER’s advanced scenarios are limited by conservativism rather than technical capabilities ($P_{fus} \rightarrow 800$ MW, $P_{heat} \rightarrow 110$ MW)
the need for physics-technology integration

Some of the key issues arise at physics-technology interface:

- Past, recognized examples are:
  - Tritium retention
  - Consequences of halo currents & vertical disruptions
  - Life – time issues in steady state
  - .......

- Others:
  - Diagnostics (incl. real time control) in nuclear environment
  - RWM-stabilisation in a device with superconducting coils
  - .......

Cannot be substituted by paper work:
Reactor studies need feet on the ground
ITER’s mission: physics & technology integration
role of R&D phase

steps in physics & technology integration
1. design
2. R&D
3. construction
4. operating experience

example: vacuum vessel segment

proof of accuracy in manufacturing and welding with 3 mm accuracy
(also proof of international collaboration: a US-produced welding robot welded a Russia-produced port to the Japan-produced vessel)

steps (1) and (2) accomplished during Engineering Design Activity 1992 - 2001:
investment and value of prototypes: 400 M€ for the 7 large projects
development path centered around ITER: the US version
development path centered around ITER: a EU tokamak version (stellarator versions exist)
• the design review of ITER has confirmed that there are no show stoppers

• two areas identified as requiring further R&D are already at the top of the EU-list
  • ELM-mitigation
  • tritium inventory

  where we have a major R&D effort, involving also US collaboration (Pisces) and a range of alternative options

• in two areas US codes have highlighted the need for re-assessment or minor modifications
  • LHCD current drive efficiency for advanced scenarios
  • RWM stabilization requirements
US left ITER when we had no site proposal.

Now we have 4 sites:

- Cadarache, EU
- Vandellos, EU