ITER as a Physics Experiment

K. Lackner, D. Campbell and many others
EFDA-CSU
D-85748 Garching

ITER exploitation phase subdivided into two sub-phases*)

• the first 10 years corresponding to an experimental physics oriented programme,

• the following 10 years to an intensive, technology oriented, use of the facility.

*) EDA Final Design Report
ITER’s role

• baseline („conventional“) scenarios: Elmy H-mode Q = 10 and „hybrid“ scenario
  
  **single confinement barrier**

  physics: extrapolation of well understood regime to/in
  - self heating
  - physics of a-particles
  - divertor & PSI

  – identifiable milestone
  – technology - physics integration
  – technology test & demonstration

• advanced scenarios:
  
  **multiple confinement barriers**

  develop physics: (a range of scenarios exist)
  - extrapolation of regime
  - self-consistency of equilibria
  - MHD stability
  - compatibility with divertor requirements and impurity concentrations
  - compatibility with satisfactory a-confinement
  - controllability

  – satisfy steady state objective
  – prepare DEMO
Standard inductive scenarios

- verify & extend our scalings and theory models (confinement, H-mode access, ELMs, NTMs..)
- qualify a-particle heating as a heating method
- high power/long pulse (on wall equilibration time) test of plasma wall interaction (incl. tritium inventory control)

maintain momentum: demonstrate milestone
  o fusion community must show public&politics identifiable progress
  o needed also for continuing support of alternatives
### Q= 10 reference scenario(s): milestone

<table>
<thead>
<tr>
<th>Parameter</th>
<th>400 MW</th>
<th>560 MW</th>
<th>260 MW</th>
</tr>
</thead>
<tbody>
<tr>
<td>R/a (m/m)</td>
<td>6.2/2.0</td>
<td>←</td>
<td>←</td>
</tr>
<tr>
<td>κ₀5/δ₀5</td>
<td>1.7/0.33</td>
<td>←</td>
<td>←</td>
</tr>
<tr>
<td>Bₜ (T)</td>
<td>5.3</td>
<td>←</td>
<td>←</td>
</tr>
<tr>
<td>Iₚ (MA)</td>
<td>15.0</td>
<td>←</td>
<td>←</td>
</tr>
<tr>
<td>q₀5</td>
<td>3</td>
<td>←</td>
<td>←</td>
</tr>
<tr>
<td>&lt;nₑ&gt; (10 ^20 m⁻³)</td>
<td>1.01</td>
<td>1.18</td>
<td>0.83</td>
</tr>
<tr>
<td>&lt;nₑ&gt;/n_G</td>
<td>0.85</td>
<td>1.0</td>
<td>0.7</td>
</tr>
<tr>
<td>&lt;Tₑ&gt; (keV)</td>
<td>8.8</td>
<td>9.0</td>
<td>8.7</td>
</tr>
<tr>
<td>&lt;Tₑ&gt; (keV)</td>
<td>8.0</td>
<td>8.2</td>
<td>7.9</td>
</tr>
<tr>
<td>P_FUS (MW)</td>
<td>400</td>
<td>560</td>
<td>260</td>
</tr>
<tr>
<td>P_NB + P_RF (MW)</td>
<td>33 + 7</td>
<td>33 + 23</td>
<td>17 + 9</td>
</tr>
<tr>
<td>Q</td>
<td>10</td>
<td>←</td>
<td>←</td>
</tr>
<tr>
<td>P_RAD (MW)</td>
<td>47</td>
<td>71</td>
<td>30</td>
</tr>
<tr>
<td>P_LOSS/P_L-H</td>
<td>1.8 (87/48)</td>
<td>2.4 (124/53)</td>
<td>1.3 (55/42)</td>
</tr>
<tr>
<td>Bₙ</td>
<td>1.8</td>
<td>2.1</td>
<td>1.4</td>
</tr>
<tr>
<td>Bₚ</td>
<td>0.65</td>
<td>0.77</td>
<td>0.52</td>
</tr>
<tr>
<td>li (3)</td>
<td>0.84</td>
<td>0.84</td>
<td>0.85</td>
</tr>
<tr>
<td>τₑ</td>
<td>3.7</td>
<td>3.1</td>
<td>4.7</td>
</tr>
<tr>
<td>H₁₀₀₀₀₁₂</td>
<td>1.0</td>
<td>←</td>
<td>←</td>
</tr>
<tr>
<td>τₑ/τₑ</td>
<td>5.0</td>
<td>←</td>
<td>←</td>
</tr>
<tr>
<td>f₁ₑₐₓ₁ₑₐₓ (%)</td>
<td>4.3/3.2</td>
<td>4.1/3.1</td>
<td>4.1/3.1</td>
</tr>
<tr>
<td>f₁ₑ₀₁ₑ₀ (%)</td>
<td>2.0</td>
<td>←</td>
<td>←</td>
</tr>
<tr>
<td>f₁ₑ₀₁ₑ₀ (%)</td>
<td>0.12</td>
<td>0.16</td>
<td>0.10</td>
</tr>
<tr>
<td>Zₑ₀₁ₑ₀ (%)</td>
<td>1.66</td>
<td>1.77</td>
<td>1.60</td>
</tr>
<tr>
<td>V_LOOP (mV)</td>
<td>75</td>
<td>75</td>
<td>82</td>
</tr>
</tbody>
</table>

*conservative requirements*
high confidence level in attainment of $Q = 10$
results of targeted R&D

- previous major concern: high H-factor at $n/n_{GR} > 0.85$

- NTMs:
  - active ECRH-feedback
  - self-limitation: FIR-modes (AUG/JET)
  - control of sawteeth (JET)
Q =10: ITER-simulation discharges on JET

JET-operating space

<table>
<thead>
<tr>
<th>SHAPING</th>
</tr>
</thead>
<tbody>
<tr>
<td>JET</td>
</tr>
<tr>
<td>&quot;ITER shape&quot;</td>
</tr>
<tr>
<td>Pulse No: 53299, 2.5MA/2.7T</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>ITER</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>Parameter</th>
<th>JET</th>
<th>ITER</th>
</tr>
</thead>
<tbody>
<tr>
<td>H_{98}(\nu/2)</td>
<td>0.91</td>
<td>1.0</td>
</tr>
<tr>
<td>\beta_{N,th}</td>
<td>1.90</td>
<td>1.81</td>
</tr>
<tr>
<td>n_e/n_{GW}</td>
<td>1.1</td>
<td>0.85</td>
</tr>
<tr>
<td>Z_{eff}</td>
<td>1.5</td>
<td>1.7</td>
</tr>
<tr>
<td>P_{rad}/P_{tot}</td>
<td>0.40</td>
<td>0.58</td>
</tr>
<tr>
<td>\kappa, \delta</td>
<td>1.74, 0.48</td>
<td>1.84, 0.5</td>
</tr>
<tr>
<td>q_{95}</td>
<td>3.2</td>
<td>3.0</td>
</tr>
<tr>
<td>\tau_{pulse}/\tau_{E}</td>
<td>15</td>
<td>110</td>
</tr>
</tbody>
</table>
Q =10: divertor issues

- divertor & plasma wall interaction issues (ELM tolerance, tritium):
  - determine pulses: how long & how often
  - has to be solved for any kind of fusion reactor
  - focussed effort starts bearing fruit
    • type 2 ELMs
    • control of C erosion & tritium co-deposition by surface temperature control
    • viability of W-solution
    • Be-experiments on Pisces
a-particle confinement:
- classical confinement good (ripple reduction through ferromagnetic inserts)
- AE-modes: for "nominal" (monotonic) q-profiles (PENN, Mishka):
  - linearly stable or
  - weak redistribution of a-particles
- fishbones: (marginally) unstable for nominal parameters

sawteeth:
- period extended by a-particle stabilisation
- 30% central T-excursion
- small effect on heat flux
Extend scaling and verify theory: confinement

• global scaling

- pedestal scaling
  - pressure gradient limited
  - spatial scale? $R^\alpha \rho^{1-\alpha}$

- profile stiffness
  - agreement with codes
  - role of self-generated shear-flows
  - electron transport

- role of $n/n_{GR}$ vs $n^*$
hybrid scenario: conservative scenario for technology testing
advanced tokamak operation on ITER

• satisfy „steady-state“ objective
• prepare DEMO (i.e. characteristics of a commercially viable reactor)
  – blue ribbon „fast track“ panel
  – fusion industry committee

• associated physics issues match ITER capabilities
  – a-physics compatibility
  – long pulse aspects
    • current profile
    • plasma surface interaction
  – heating power > current drive power
    • controllability
steady state („advanced“) scenarios:

- development needed
- spectrum of scenarios
- scenarios illustrative

<table>
<thead>
<tr>
<th>Scenario 4</th>
<th>Scenario 6</th>
<th>Scenario 7</th>
</tr>
</thead>
<tbody>
<tr>
<td>WNS</td>
<td>WNS</td>
<td>SNS</td>
</tr>
<tr>
<td>R/a (m)</td>
<td>6.35/1.85</td>
<td>6.35/1.85</td>
</tr>
<tr>
<td>B_T (T)</td>
<td>5.18</td>
<td>5.18</td>
</tr>
<tr>
<td>I_p (MA)</td>
<td>9.0</td>
<td>9.5</td>
</tr>
<tr>
<td>\kappa_{35/35}</td>
<td>1.85/0.40</td>
<td>1.87/0.44</td>
</tr>
<tr>
<td>\langle n_e \rangle \times 10^{19} m^{-3}</td>
<td>6.7</td>
<td>7.1</td>
</tr>
<tr>
<td>n/n_C</td>
<td>0.82</td>
<td>0.81</td>
</tr>
<tr>
<td>\langle T_e \rangle (keV)</td>
<td>12.5</td>
<td>11.6</td>
</tr>
<tr>
<td>\langle T_i \rangle (keV)</td>
<td>12.3</td>
<td>12.6</td>
</tr>
<tr>
<td>\beta_T</td>
<td>2.77</td>
<td>2.67</td>
</tr>
<tr>
<td>\beta_N</td>
<td>2.95</td>
<td>2.69</td>
</tr>
<tr>
<td>\beta_p</td>
<td>1.49</td>
<td>1.25</td>
</tr>
<tr>
<td>P_{rns} (MW)</td>
<td>356</td>
<td>338</td>
</tr>
<tr>
<td>P_{PF} + P_{NP} (MW)</td>
<td>29 + 30 1.1</td>
<td>35 + 28 1.1</td>
</tr>
<tr>
<td>Q = P_{NS}/P_{add}</td>
<td>6.0</td>
<td>5.36</td>
</tr>
<tr>
<td>W_{th} (MJ)</td>
<td>287</td>
<td>292</td>
</tr>
<tr>
<td>P_{loss}/P_{LH}</td>
<td>2.59</td>
<td>2.74</td>
</tr>
<tr>
<td>\tau_E (s)</td>
<td>3.1</td>
<td>2.92</td>
</tr>
<tr>
<td>f_{H_2} (%)</td>
<td>4.1</td>
<td>4.0</td>
</tr>
<tr>
<td>f_{Be} (%)</td>
<td>2</td>
<td>2.0</td>
</tr>
<tr>
<td>f_{Ar} (%)</td>
<td>0.26</td>
<td>0.16</td>
</tr>
<tr>
<td>Z_{ref}</td>
<td>2.07</td>
<td>1.87</td>
</tr>
<tr>
<td>P_{rad} (MW)</td>
<td>37.6</td>
<td>30.6</td>
</tr>
<tr>
<td>P_{bss} (MW)</td>
<td>92.5</td>
<td>100.0</td>
</tr>
<tr>
<td>I_t (3)</td>
<td>0.72</td>
<td>0.43</td>
</tr>
<tr>
<td>I_{CD}/I_p (%)</td>
<td>51.9</td>
<td>49.7</td>
</tr>
<tr>
<td>I_{he}/I_p (%)</td>
<td>48.1</td>
<td>50.3</td>
</tr>
<tr>
<td>I_{HI}/I_p (%)</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>\theta/\theta_{Lmin}</td>
<td>5.3/3.5/2.2</td>
<td>5.0/3.8/2.7</td>
</tr>
<tr>
<td>H_{H,i} (y, 2)</td>
<td>1.57</td>
<td>1.46</td>
</tr>
<tr>
<td>\tau_{He}^*/\tau_E</td>
<td>5.0</td>
<td>5.0</td>
</tr>
</tbody>
</table>
extrapolation and extension of regime

approach to ITER s.s.-targets in dimensionless performance parameters:

the 7-fold way*)

*) + pulse length: -> only full CD,ELMy H-mode cases shown

smaller q (implied by high f_{BS}, low b_N)

JT-60U RS

JT-60U high bp

ITER & Power Plant:
higher n/n_{GW} but lower n* !

- 1MA/3T/βN~2.8
- 0.5MA/1.5T/βN~3.2
- 1.5MA/3.7T/βN~2.5
- 0.85MA/2T/βN~1.5, LH + NB
- 1.8MA/4.0T/βN~2.4

- Rev.Shear ELMyH
- High-βp ELMyH

JT-60U high bp

normalized poloidal gyroradius ρ_pl

collisionality ν_e *
self-consistency of parameters and profiles: a range of “advanced” regimes exist

Central CD+ bootstrap
\(q_{95} = 4.8, \ \beta_N = 2.5, \ H_Hy_2 = 1.4\)

Bootstrap
\(\beta_N = 2.8, \ H_Hy_2 = 1.5\)

Broad CD + high bootstrap
\(q_{95} = 9.3, \ \beta_N = 2.2, \ H_Hy_2 = 2.2\)

current hole:

JT60-U

JET: LHCD
current holes as extreme of reverse shear

current holes can also be generated exclusively by bootstrap current (JT60-U)

current-distribution stable, decaying only because of residual $V_{\text{loop}}$

bootstrap current: efficient generation in low-$B_{\text{pol}}$-region

high energy density plasma confined by barrier

but large excursions of ions in $B_{\text{p}}$-free zone (example 4keV ions in JT60-U)
a-particle physics and self-heating in advanced scenarios

significantly more problematic than in standard scenarios

to allow study of instability effects: improve „classical confinement“ – ferritic inserts

\[ \omega^* = 2nq^2 \rho^{*2} \left( R \omega_{pl} / c \right) \]

„synergies“ between AE core losses and ripple edge losses?
heating & current drive systems

P_{add} for Q= 10 nominal scenario: 40 MW

<table>
<thead>
<tr>
<th>heating system</th>
<th>stage I</th>
<th>possible upgrade by</th>
<th>remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>NBI (1 MeV negative ion)</td>
<td>33</td>
<td>16.5k</td>
<td>vertically steerable (z at R_{wa} = 0.42 m to +0.18 m)</td>
</tr>
<tr>
<td>ECR H&amp;CD (170 GHz)</td>
<td>20</td>
<td>20</td>
<td>equatorial port &amp; upper port turner; steerable</td>
</tr>
<tr>
<td>ECR H&amp;CD (40 – 60 MHz)</td>
<td>20</td>
<td>(20% 50% power to ions), (30% 70% to ions); FW CD</td>
<td></td>
</tr>
<tr>
<td>LH H&amp;CD (5 GHz)</td>
<td>20</td>
<td>1.8σn&lt;2.2</td>
<td>upgrade in different RF combinations possible</td>
</tr>
<tr>
<td>ECRH startup system (120 GHz)</td>
<td>2</td>
<td></td>
<td>start-up gyr.</td>
</tr>
<tr>
<td>Diagnostic Beam 300 keV H, neg. ion?</td>
<td>&gt;2</td>
<td></td>
<td>top-launch</td>
</tr>
</tbody>
</table>

NBI-layout

ECR-feeding

DB

power routing

midplane

top-launch

start-up gyr.
# Heating & Current Drive Systems

<table>
<thead>
<tr>
<th>Heating System</th>
<th>Stage</th>
<th>Possible Upgrade</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>NBI (1 MeV negative ion)</td>
<td>33</td>
<td>16.5%</td>
<td>Vertically steerable ( \pm 0.4 \text{m} ) to ( \pm 0.16 \text{m} )</td>
</tr>
<tr>
<td>ECR H&amp;CD (170 GHz) (+2 MW 120 GHz for startup)</td>
<td>20</td>
<td>20</td>
<td>Equatorial port&amp; upper port buncher; steerable</td>
</tr>
<tr>
<td>ECR H&amp;CD (80 – 60 MHz)</td>
<td>20</td>
<td>20</td>
<td>( 2 \Omega ), 50% power to ions; ( \Omega ), 70% to ions; FM CD</td>
</tr>
<tr>
<td>LH H&amp;CD (56 MHz)</td>
<td>20</td>
<td></td>
<td>( 1.8 &lt; n_e &lt; 2.2 )</td>
</tr>
<tr>
<td>Total</td>
<td>73</td>
<td>130</td>
<td>Upgrade in different RF combinations possible</td>
</tr>
</tbody>
</table>

### IC Power Absorption by Species

![IC power absorption by species](image)

- LH-launcher; based on Passive-Active Multi-junction principle

*) to be tested on FTU, Tore-S.
the JET ICRH ITER-like antenna (2005)

- 7.5 MW at ITER relevant coupling (2-4 W/m)
- High coupling efficiency (90%) in range 30<f<55 MHz
- ELM resilient

preparatory physics R&D for ITER heating in JET

strong effort to increase LH availability in combination with other heating systems

![Graph showing plasma heating data](image-url)
high field side pellet launch

<table>
<thead>
<tr>
<th>type</th>
<th>number of injectors</th>
<th>repetition frequency</th>
<th>size</th>
<th>velocity</th>
<th>pulse length capability</th>
</tr>
</thead>
<tbody>
<tr>
<td>high field side;</td>
<td>2 (3)</td>
<td>7 – 50 Hz</td>
<td>3 - 6 mm</td>
<td>&lt; 0.5 km/s</td>
<td>3000 s</td>
</tr>
<tr>
<td>centrifuge</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

benefit for high-bp ELMy H-mode

inward shift of mass deposition with respect to ablation

Figure 4.5-2 Model Predictions for the HFS Injection in ITER
Solid lines correspond to pellet ablation, dashed lines for the ablated mass deposition

benefit of pellet injection on reverse shear modes: still to be explored
advanced scenarios at high $b_n$ require RW feedback stabilisation

standard regimes *(high $l_i$)*

advanced regimes *(low $l_i$)*

ITER error field correction and RWM control coils

potential gain by low-n RWM feedback
divertor compatibility and impurity control

Impurity density development in ITB discharges on JET (similar on JT-60U):
- no accumulation low and med. Z
- accumulation of high-Z

W-experience on AUG:
- central (electron) heating suppresses accumulation: a-heating!

---

Impurity density development in ITB discharges on JET (similar on JT-60U):
- no accumulation low and med. Z
- accumulation of high-Z
flexibility through divertor maintenance and exchange capability

for refurbishment and design-improvements

divertor cassette system allows replacement of divertor within 6 months:
relevant & attractive range of plasma shapes covered:

<table>
<thead>
<tr>
<th></th>
<th>FDR</th>
<th>FEAT</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\kappa_{95}/\kappa_x$</td>
<td>1.6 / 1.76</td>
<td>1.7 / 1.86</td>
</tr>
<tr>
<td>$\delta_{95}/\delta_x$</td>
<td>0.24 / 0.31</td>
<td>0.35 / 0.45</td>
</tr>
</tbody>
</table>

enhanced shaping viz. ITER-FDR

Double-Null proximity (+triangularity) for access to type II ELMs

FEATFDR enhanced shaping viz. ITER-FDR can be further pushed to accommodate important observations

Double-Null proximity (+triangularity) for access to type II ELMs

AUG

ITER

Reference plasma

advanced scenarios - > stronger shaping possible ($I_p = 9$ MA)

<table>
<thead>
<tr>
<th>$l_i$</th>
<th>0.6</th>
<th>0.4</th>
</tr>
</thead>
<tbody>
<tr>
<td>$k_{95, ma}$</td>
<td>&lt;2</td>
<td>&lt;2.1</td>
</tr>
</tbody>
</table>
controllability:

long pulse feedback control of JET ITB discharges

\[ \rho_{ITB} \geq \text{ITB existence criterion and control parameter} \]

\[ \rho_{r} = \rho_{s} / L_{r} > \rho_{ITB} \]

LHCD used to delay current profile development
**pulse length & duty cycle**

<table>
<thead>
<tr>
<th>scenario</th>
<th>burn time*</th>
<th>burn time**</th>
</tr>
</thead>
<tbody>
<tr>
<td>inductive, (reference)</td>
<td>500</td>
<td></td>
</tr>
<tr>
<td>hybrid</td>
<td>1000</td>
<td></td>
</tr>
<tr>
<td>steady-state</td>
<td>3000**</td>
<td></td>
</tr>
</tbody>
</table>

*) repetition time = 4 x burn time

**) (at present) limited by external cooling capacity

- High availability: ample time & opportunity for experiments
- (although observation of current diffusion on $t \sim t_{\text{skin}}$)
  - execution of control: $t \gg t_{\text{skin}}$

Moreau: simulation of ITER-FDR *) feedback control with fuelling, FWCD & LHCD

*) reduce times by factor of 2 for ITER-FEAT
diagnostic access & facilities

ITER

UPPER PORT

NORTH

1. Active Spectr (MSE)
   Neutron Act syst (\(^{18}\text{N}\))

2. H-alpha / Vis spec (inner edge)
   Main plasma reflect.

3. Neutron Camera

4. CXRS (pol rot - DNB)
   Wide angle viewing/IR

5. Neutron Camera
   Neutron Act syst (\(^{18}\text{N}\))

6. Neutron Camera
   Neutron Act syst (foil)

7. Neutron camera
   Wide angle viewing/IR

8. Bolometry
   Position Reflectometry

9. H-alpha/Vis. spec (upper edge)

10. VUV,
    X-ray Crys Array
    Neutron Act syst (foil)

11. Edge Thomson scattering
    Wide angle viewing/IR

14. Wide angle viewing/IR
    Position Reflectometry

16. Bolometry
    Soft X-Ray
    Divertor Impurity (div16)

18. Wide angle viewing/IR
    H-alpha/Vis. spec (outer edge)

all In-vessel diagnostic wiring
diagnostic access & facilities

EQUATORIAL PORT

3 Wide angle viewing/IR
CXRS (with DNB)
MSE (with heating NB)
H-alpha/Vis spect (Div).

4 DNB
7 Obscured port

8 RH plus Limiter
Neutron flux monitor

9 Wide angle viewing/IR
Tor./Inteter. polarimeter
ECE
Fast Wave Reflectometry
(possibly) MSE

10 LIDAR Thomson Scattering
Polarimeter

11 X-ray Cryst spec
NPA
VUV (main & div.)
Reflectometry

12 Wide angle viewing/IR
H-[] Vis. spec (upper edge)
Vis. continuum array

16 Wide angle viewing/IR
Radial Neutron Camera
Bolometry
Soft x-ray array
Divertor Impurity (div 16)

17 RH plus Limiter
Neutron flux monitor
Neutron Act syst (foil & ^15N)

Unassigned:
Collective scattering

DIVERTOR

2 VUV Impurity Monitor (g)
IR Thermography (c)
Langmuir Probes
Magnetics Thermocouples

4 CXRS(c)
Dust measurement(g),
Magnetics

8 Reflectometry/Interferometry(g)
LIF (c)
Bolometry, Magnetics
Pressure Gauges

10 X-point LIDAR (c)
Div Thomson Scattering (g)
Bolometry, Magnetics
Langmuir Probes
Pressure Gauges,

14 Reflectometry/Interferometry (g)
Plate Erosion (c)
Magnetics, Thermocouples
Langmuir Probes

16 Visible Div Impurity Monitor (c,g)
Bolometry, Magnetics
Pressure Gauges,
Thermocouples

Alloc 7-5-02
ITER’s role for alternatives (e.g. stellarator):

- understand physics of a-particle heating,
- develop PSI solutions
- ...

[Diagram showing connections between ITER, LHCD, W7X, NCSX, THEORY, DEMO, MATERIALS, and COMMERCIAL PP]
ITER's role for alternatives (e.g. stellarator)
ITER: possibly different role in fusion strategy of EU, Japan & Russia and USA
public and political attitude towards fusion R&D in Europe

exemplified by hearing in German parliament: questions (and answers by IPP, FZJ,FZK) in English translation http://EFDA.ipp.mpg.de/portal/add_info/debates.htm->Hearing on Nuclear Fusion / engl.

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examples:

C.1. What steps with what estimated costs in what period must be taken until an economically usable fusion reactor will be available.

C.4. What have been the costs of total fusion research up to the present?

C.5. What have been the costs of preparing for the ITER project since 1985 ? How much is publicly financed and how much comes from industry ?

C.6. How high are the costs estimated for a first test reactor, a later planned second test reactor and the further development steps up to first commercial electricity production ?

C.7. Can the costs of approx. DM 150 billion including over DM 50 billion estimated to arise in the EU specified in the recent TA study "Advanced Nuclear Systems" by the Swiss Science Council for the ITER path be confirmed ?
to fulfill ITER’s missions

ITER must carry out an extensive and ambitious physics programme

its essential design features give it also capability to do this

– pulse length and duty cycle
– diagnostic access & facilities
– flexible heating, current drive system
  • total power
  • composition
– other plasma engineering systems
  • inside pellet launch
  • RWM feedback
– divertor exchange capability
– shape flexibility

ITER operating scenarios

• base-line: high confidence
• advanced: good prospects, broad spectrum, exciting physics

EU-tokamak programme (in coll. with Japan & US)

proves compatibility between ITER relevance & programmatic width

• solve H->10 critical issues
  • n/nGR ->1
  • NTMs
• identify approaches to physics/technology interface issues
  • ELMs, tritium inventory
• prepare steady-state/advanced operating scenarios