International Collaboration Opportunities for the US Fusion Sciences Program

International Collaboration Task Group, US BPO

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PPPL
FESAC
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Outline

1. Purpose of study
2. Criteria, Methods & Challenges
3. ReNeW Issues For International Collaboration
4. Assessment Opportunities for Enhanced Collaboration
5. Timescales and Findings
International Collaboration Task Group, BPO

Charge
Evaluate and prioritize the opportunities for US collaboration on EAST, KSTAR, JET, and JT60SA to prepare for US participation on ITER and to address the issues and gaps discussed in the recent report "Issues, Gaps, and Opportunities: Towards a Long-Range Strategic Plan for Magnetic Fusion Energy", DOE-SC-0102.

Members
• D. Humphreys
• C. Kessel \hspace{1cm} (Resigned to head Pathways Study)
• T. Luce
• S. Milora
• S. Sabbagh
• D. Whyte
• M. Zarnstorff (Chair)
Motivation: International Collaboration more Important

• Preparation for ITER. Intrinsically an international collaboration

• Some high priority ReNeW / Greenwald-panel issues require capabilities not available in US
  – Long-pulse, superconducting coils
  – Stellarators
  – Larger scale and burning plasmas

• Invitations for US to Partner on International Facilities, with shared responsibility and financing
  – Wendelstein 7-X: whole program
  – JET: Extension past 2014 & DT program
  – BA: IFMIF & JT-60SA
  – Requests to strengthen: KSTAR, EAST, LHD
Criteria for Comparison of Opportunities

• Address and resolve critical fusion research issues
  — ReNeW and FESAC reports,
  — Cannot be resolved on present US facilities

• Maintain and develop key US strengths

• Prepare for participation in ITER and further steps towards fusion energy.

In addition: US collaboration should have impact.
Methods for Enhanced Collaboration

• To address US priorities & involve US community, US needs to contribute resources

• To achieve key challenging goals, US may need to make substantial investments and commitments
  – Take responsibility for parts of program on foreign facility
  – Dedicate staff; equipment
  – Continuous engagement
  – Partnership (as on ITER)

• To be successful, should be synergistic for both parties
  Requires US to have & maintain relevant expertise

• Requires open communication, commitment by all parties
Challenges of International Collaboration

• Different national programs have different goals & constraints

• Host sets priorities – loss of control

• Planning required to maintain or develop US scientific leadership
  – Explicit agreements with host for responsibilities
  – Use of resources to explore novel ideas
  – Coordinate with domestic activities to maintain expertise & value, bring knowledge gained into US program

• Challenging for US personnel
  – Families
  – Relocated personnel may not return
### International Facilities: Technical Opportunities

<table>
<thead>
<tr>
<th></th>
<th>JET</th>
<th>AUG</th>
<th>EAST</th>
<th>KSTAR</th>
<th>JT-60SA</th>
<th>MAST</th>
<th>LHD</th>
<th>W7-X</th>
<th>RFX</th>
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<td>1.5</td>
<td>2</td>
<td>5.5</td>
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<td>&lt; 0.1</td>
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<td>3.3</td>
<td>4.1</td>
<td>3.6</td>
<td>2.5</td>
<td>0.3</td>
<td>11</td>
<td>4.4</td>
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<tr>
<td>configuration</td>
<td>SN</td>
<td>SN (DN)</td>
<td>DN</td>
<td>DN</td>
<td>DN</td>
<td>DN/SN</td>
<td>3D, helical</td>
<td>RFP</td>
<td>3D, quasi-isodyn.</td>
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<td>kappa, delta</td>
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<td>1.9, 0.65</td>
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<td>n=4</td>
<td>-</td>
<td>n=2</td>
<td>n &gt; 1</td>
<td>n=6</td>
<td>n=5, m=1</td>
<td>n=5, m=1</td>
<td>n =24, m=2</td>
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<td>36</td>
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<td>Cu</td>
<td>Cu</td>
<td>SC</td>
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<td>SC</td>
<td>SC</td>
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<td>pulse length (s)</td>
<td>20</td>
<td>10</td>
<td>1000</td>
<td>300</td>
<td>100</td>
<td>1</td>
<td>~3600</td>
<td>1800</td>
<td>~0.2</td>
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</table>

- Key characteristics not available in US facilities
- Important collaboration activities and opportunities on all
ReNeW Issues: Key Characteristics of International Facilities

- Steady-state / very long pulse: SC coils
- Large scale tokamaks & stellarator - closer to burning plasmas
- DT plasmas
- Other ITER-like characteristics
  - PFC materials;
  - In-vessel control coils
- Novel divertor geometries, 2D & 3D
- Actively cooled internal components; thermally equilibrated; high temp.
- Remote maintenance
Many ReNeW Issues Only Accessible by International Facilities

• Tabulated in Section 3 of Report

• Only considered existing facilities or those under construction

• Issues in every thrust, every topical area
  Includes technology issues

• Current International Facilities do not cover all issues
  Opportunities for new or upgraded domestic facilities.
  => Need balance between domestic and collaborations
Plans and Opportunities Assessed
For each Confinement Facility

Section 4
- Facility technical capabilities & development plans
- Technical importance to US program
  Which ReNeW issues can be resolved?
- Opportunities for enhanced US collaboration
  Synergy with US program, opportunities for leadership
  Potential for impact by US participation or partnership
  Timescales
  Specific challenges?

Greatest opportunities:  EAST, JET, JT-60SA, KSTAR, W-7X
### Ability to Impact ReNeW Issues Assessed

<table>
<thead>
<tr>
<th>Th 1: Measurement techniques for burning plasma</th>
<th>EAST</th>
<th>JET</th>
<th>JT-60SA</th>
<th>KSTAR</th>
<th>W7-X</th>
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<tbody>
<tr>
<td>Long-pulse steady-state diagnostics</td>
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<td>Long-pulse machine protection</td>
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<td>Develop DEMO prototypical alpha diagnostics</td>
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<td>Remote maintenance and calibration of diagnostics</td>
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<tr>
<th>Th 2: Control of transient events in burning plasma</th>
<th>EAST</th>
<th>JET</th>
<th>JT-60SA</th>
<th>KSTAR</th>
<th>W7-X</th>
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<tbody>
<tr>
<td>Long-pulse ITER prototype regime, without ELMs &amp; disruptions</td>
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<tr>
<td>Test extrapolation of ELM &amp; disruption avoidance and mitigation to larger scale</td>
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<tr>
<td>Long pulse instability control at high beta-N</td>
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<tr>
<th>Th 3: Role of Alpha particles in burning plasma</th>
<th>EAST</th>
<th>JET</th>
<th>JT-60SA</th>
<th>KSTAR</th>
<th>W7-X</th>
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<tbody>
<tr>
<td>Validate understanding of effect of fast-ion instabilities in steady-state scenarios, at larger scale</td>
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<tr>
<td>Understand interactions between fast-ion and global MHD instabilities in steady-state scenarios</td>
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<td>Impact of fast on losses on first wall in steady scenarios</td>
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<td>Test control of alpha heating profile</td>
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<tr>
<th>Th 4: Qualify operating scenarios and physics for ITER</th>
<th>EAST</th>
<th>JET</th>
<th>JT-60SA</th>
<th>KSTAR</th>
<th>W7-X</th>
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<tbody>
<tr>
<td>ITER scenarios with DT, including alpha particles (with ITER-like PFCs)</td>
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<td>ITER scenarios with superconducting coils, relevant H&amp;CD methods, long pulse</td>
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<td>PFC cleaning for long-pulse</td>
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<td>Test ITER fueling and pumping at largest scale</td>
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<tr>
<td>Development of burn control strategies (sim.)</td>
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<tr>
<th>Th 5: Expand limits for controlling and sustaining fusion plasmas (tokamaks)</th>
<th>EAST</th>
<th>JET</th>
<th>JT-60SA</th>
<th>KSTAR</th>
<th>W7-X</th>
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<tr>
<td>Maintain AT scenarios suitable for high fusion power gain for long pulse, restricting diagnostics &amp; actuators</td>
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<tr>
<td>Determine min. diagnostic &amp; actuator set needed for high fusion power gain long pulse</td>
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<tr>
<td>Develop &amp; demonstrate long-pulse fueling &amp; exhaust systems</td>
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</table>
Of the SC tokamaks, EAST will have earliest integrated capability
Opportunities for Enhanced Collaboration With Highest Impact

- **JET**: ITER operating scenarios with DT plasmas & ITER-like walls & largest available scale. Reduce risks for ITER, e.g., validating ITER chosen methods to suppress ELMs and avoid and mitigate disruptions.

- **W 7-X**: Disruption-free high-performance confinement in a large-scale optimized stellarator, operating limits, compatibility with divertors.

- **EAST**: Long-pulse PMI with prototypical metallic walls (tungsten and/or lithium), including high ambient wall temperature.

- **EAST and KSTAR**, followed by **JT-60SA**: Steady-state, high-performance confinement in tokamaks, including operating limits, ability to operate disruption-free, and compatibility with divertors. EAST will have earliest capability. JT-60SA will have largest scale.
Timely Decisions Required

- **JET** invitation for US partnership: need to start immediately.

- To participate in aggressive **EAST** program, need to dedicate resources quickly.

- **W-7X** invitation for US partnership: must decide level in next couple of years, before niches fill.

- Impact of **KSTAR** collaboration can be strengthened with increased funding.

- Level of **JT-60SA** participation and timing should be explored.
Activities

• Conference calls

• Input from facilities (EAST, JET, JT-60SA, KSTAR, LHD, MAST, RFX-mod, W7-X)

• Presentations at PAC meetings, conferences, workshops, coordination meetings

• JET-RMP, JET-ECH, and W7-X collab. Proposals

• Visits to facilities

• Requested & received input from
  – BPO Research Committee
  – VLT leadership
  – International Collaboration Leaders in US